MAGNETIC PRODUCTS

DATA HANDBOOK

Piezoelectric Ceramics
Specialty Ferrites

BOOK MA03 1993

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Piezoelectric Ceramics Specialty Ferrites

Contents

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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.	

PIEZOELECTRIC CERAMICS

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.

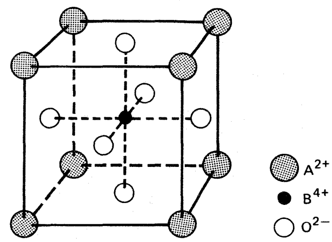


Fig.1 The perovskite crystal structure.

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.

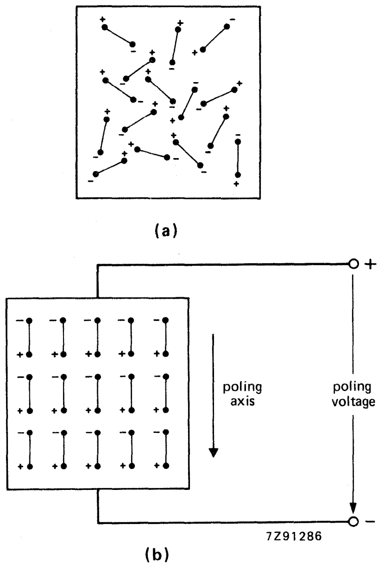
Piezoelectric effect in ceramic materials

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.



(a) Before polarization.

(b) After polarization (ideal conditions).

Fig.2 Electric dipoles (of the domain) in piezoelectric materials.

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.

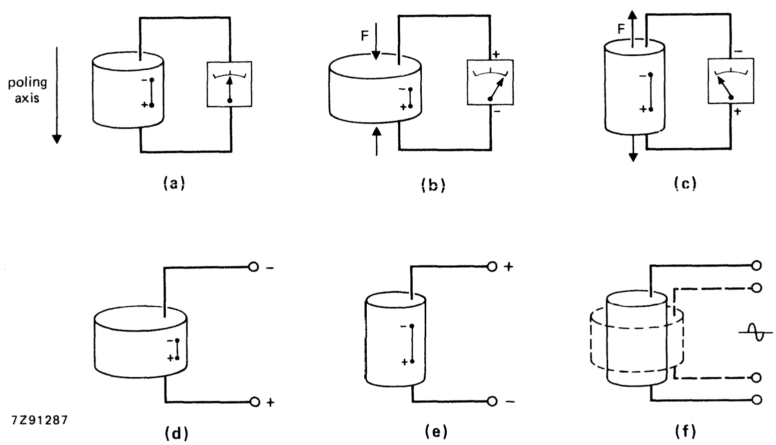


Fig.3 The piezoelectric effect on a cylindrical body of piezoelectric ceramic. For the sake of clarity, only one dipole is shown.

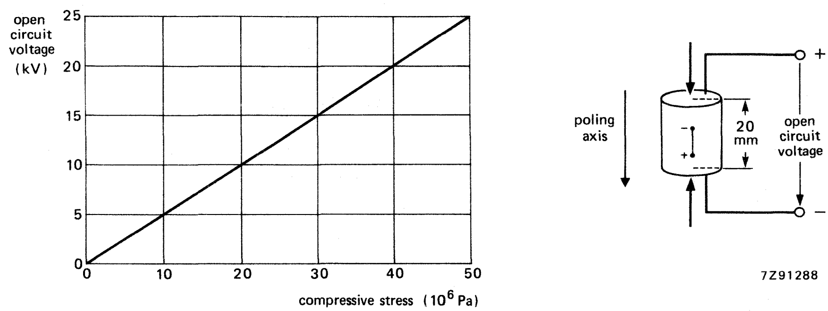


Fig.4 Open circuit voltage of a 20 mm long piezoelectric ceramic cylinder as a function of compressive stress applied.

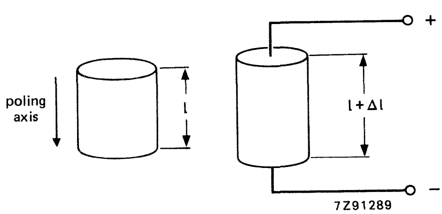


Fig.5 Elongation of a cylindrical piezoelectric ceramic body caused by a DC voltage.

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 50 000 kPa at which point the generated voltage equals 25 kV.

The maximum piezoelectric induced strain, Δl/l (Fig.5), in a PXE 5 cylinder is around 5 x 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
- Fuzes 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, e.g. for telephones
- Intruder alarm systems
- Remote control
- Loudspeakers, e.g. tweeters
- Audio tone generators in signalling devices.

Sensors

- Record players
- Accelerometers
- Detection systems in machinery, e.g. textile
- Medical equipment
- Motor cars, e.g. 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.

Actuators

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

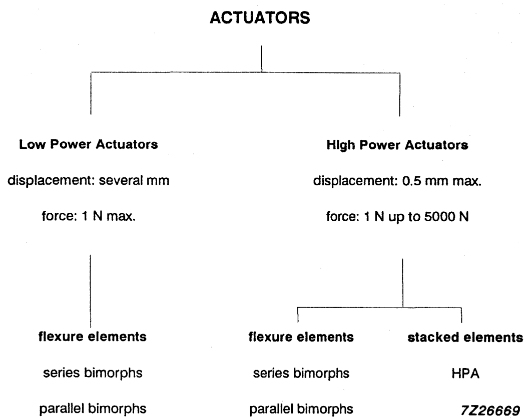


Fig.6 The actuator family.

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 dismatch 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.

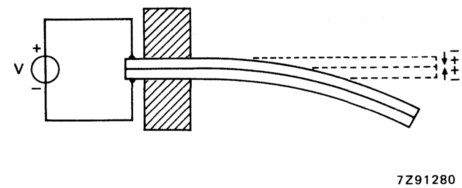


Fig.7 Series bimorph.

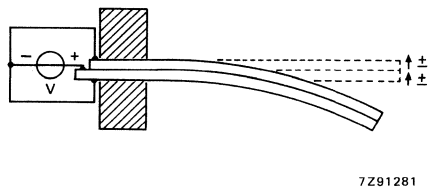


Fig.8 Parallel bimorph.

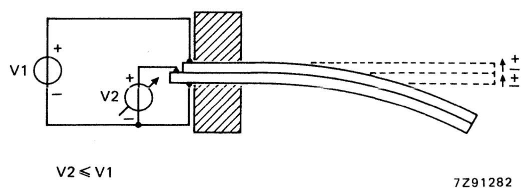


Fig.9 Parallel bimorph with bias voltage drive.

Practical design data for PXE 5 flexure elements

l_t = total length
F = force on tip
W = width
l = free length
h = total thickness
z = deflection of tip.
Field strength: max. 500 V/mm.

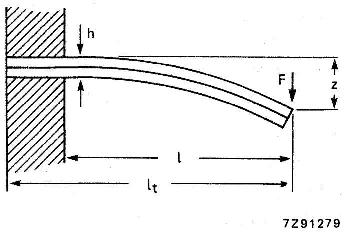


Fig.10 Flexure element (bimorph).

PARAMETER	PARALLEL	SERIES	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	$10^{-2} \frac{l^2}{h\, l_t W}$	$2 \times 10^{-2} \frac{l^2}{h\, l_t W}$	V/N

Piezoelectric ceramics for 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:

$$L = \frac{1}{(4\pi^2 f^2 C_o)}$$

The impedance of the transducer then appears as purely ohmic.

DESCRIPTION OF SYMBOLS

ε_0 = dielectric constant of free space = 8.85 x 10^{-12} F/m

$\varepsilon^T{}_r = \varepsilon^T/\varepsilon_0$ = relative dielectric constant at constant stress

$\varepsilon^T{}_r = \varepsilon^S/\varepsilon_0$ = relative dielectric at constant strain

tan δ = 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 FORMULAE

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:

(1) $P = dT$

in which d is a material constant known as the: piezoelectric charge constant. (Note: 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:

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

in which ε^T is the permittivity, itself a stress-dependent quantity. To a first approximation, this dependence can be neglected and (1) and (2) combined to give

(3) $dT = D - \varepsilon^T E$, or $D = dT + \varepsilon^T E$

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

(4) $E = - gT + D/\varepsilon^T$

where $g = d/\varepsilon^T$ is known as the piezoelectric voltage constant.

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:

$S = dE$ or $S = gD$.

The strain experienced by an elastic medium subjected to a tensile stress T is according to 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:

(5) $S = S^E T + dE$ or

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

in which S^E and S^D are respectively the specific compliancies at constant electric field and constant electric displacement.

Note: in SI units, d is expressed in C/N (or its equivalent m/V), and g is expressed in Vm/N (or its equivalent m^2/C).

Coupling factor k

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

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

with $k^2 = d^2/(S^E\, \varepsilon^T)$

or $k^2/(1 - k^2) = g^2 \varepsilon^T / S^D$.

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 = stored energy converted / stored input energy

k is referred to as the coupling factor.

This formula holds for both electro-mechanical 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. Relations (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 electro-mechanical 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 2 provides a guide for these limits.

Table 2 Electrical and mechanical limits

PXE GRADE	ELECTRIC FIELD STRENGTH (V/mm)	MECHANICAL PRE-STRESS (MPa)
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:

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

e^T_{33} 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 $\varepsilon_r = \varepsilon/\varepsilon_0$ (the absolute permittivity ε_0 is the permittivity of vacuum = 8.85×10^{-12} F/m.).

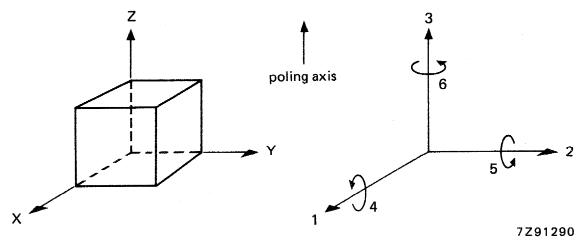


Fig.11 Designation of axis in piezoelectric materials.

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:

$s^E_{33} = 1/Y^E_{33}$ is the strain per unit stress in the 3-direction at constant electric field.

$s^D_{55} = 1/Y^D_{55}$ 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.

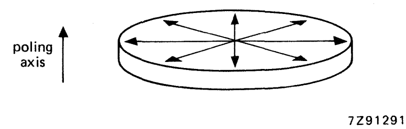


Fig.12 Planar vibration.

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:

$f_{rad} = N_p/D$

The thickness resonant frequency is:

$f_{th} = N_p/d$

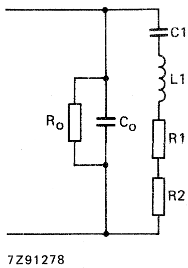
The frequency constants are equal to half the governing sound velocity in the ceramic body, except for the constant N_p.

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.



C_o = capacitance of the clamped transducer.

R_o = dielectric loss of the transducer. $[2\Pi f(C_o + C1)) \tan]^{-1}$

R1 represents the mechanical loss in the transducer.

RL represents the acoustic or mechanical load.

C1 and L1 represent the rigidity and the mass of the material.

Fig.13 Equivalent circuit.

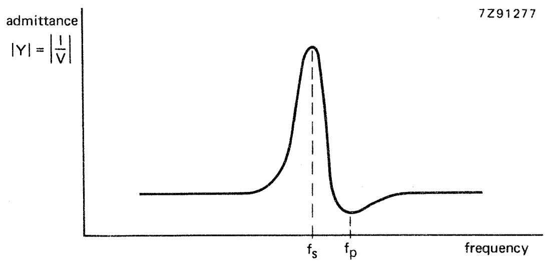


Fig.14 Admittance curve.

ORDERING INFORMATION

The products in this handbook are identified by an 11 digit code number. All physical and technical properties of the product are described by these 11 digits. It is therefore recommended for use on technical drawings and equipment parts lists.

This 11 digit code may also appear on some packing material inside boxes.

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

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 packing labels, provides full logistic information as well.

The 12th digit is used as packing indicator. Products in standard packing quantities have a last digit ranging from 1 to 6. The current number is a result of previous developments. For a range of preferred products, smaller packing units are also available for sampling and design-in support. These are identified by a '9' as the 12th digit.

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 referred to.

Label		
4322 020 0472		=11 NC product code
CH 700-704 LOT 200		=production code
BATCH 005458	BATCH	=batchnumber
ORIG A670	ORIG	=country of origin
RPC KB	RPC	=production center
QTY 10000	QTY	=quantity
DATE 9211	DATE	=production week
TYPE BIM8/4/0.61-PX5-N	TYPE	=product type description
CODENO 4322 020 04721	CODENO	=ordering code

ELECTRICAL CONNECTIONS

An electrical contact can be made by soldering, glueing 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).

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):

PbO	66%
ZrO_2	21%
TiO_2	11%.

Silver 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 in accordance with MIL STD 414 and 105D.

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 no longer 'inspected-in', but 'built-in' by continuous improvement.

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

- raw materials
- production process
- finished products.

Delivery quality

The production batches of our piezoelectric ceramic products are inspected for mechanical, electrical and visual properties. The quality of the products is in accordance with MIL-STD-105D.

A.Q.L. values are laid down as follows:

INSPECTION	A.Q.L.	INSPECTION LEVEL
Mechanical	1.00	I
Electrical	0.65	II
Visual	1.00	I

Mechanical and visual inspections follow normal procedures. Electrical inspection methods are laid down in I.R.E. standards on piezoelectric products.

For special applications, special requirements on the products are necessary: it is advised that the specification be determined in co-operation with the supplier.

MATERIALS AND GRADES

The following grades are available:

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 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 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 7/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.

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 Ø16 x 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

PROPERTY AND SYMBOL	PXE 5	PXE 52	PXE 21	PXE 41	PXE 42	PXE 43	PXE 7	PXE 71	UNIT
Thermal data									
Curie temperature	285	165	270	315	325	300	320	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	7.8	7.9	7.8	7.8	7.9	7.8	10^3 kg/m^3
Compliance									
s_{33}^E	18	20	19	15	15	13	16	–	10^{-12}/Pa
s_{11}^E	15	16	15	12	13	11	13	15	10^{-12}/Pa
s_{55}^E	39	–	–	37	–	–	33	38	10^{-12}/Pa
Poisson's ratio σ	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	
Mechanical quality factor for radial mode Q_m^E	75	65	75	1200	750	1000	80	80	
Frequency constants									
N_P^E	1975	1925	2000	2175	2200	2350	2200	2100	Hz m or m/s
$N_3^D = \frac{1}{2}\upsilon_3^D$	1850	1800	1900	2000	2015	2050	–	–	Hz m or m/s
$N_1^E = \frac{1}{2}\upsilon_1^E$	1450	1400	–	1620	–	–	1600	1500	Hz m or m/s
$N_5^E = \frac{1}{2}\upsilon_5^E$	930	–	–	950	–	–	1000	920	Hz m or m/s
Compressive strength	>600	>600	>600	>600	>600	>600	>600	>600	10^6 Pa
Tensile strength	80	80	80	80	80	80	80	80	10^6 Pa

PROPERTY AND SYMBOL	PXE 5	PXE 52	PXE 21	PXE 41	PXE 42	PXE 43	PXE 7	PXE 71	UNIT
Electrical data									
Relative permittivity ($\varepsilon_0 = 8.85 \times 10^{-12}$ F/m)									
$\varepsilon_{33}^T/\varepsilon_0$	2100	3900	2000	1225	1325	950	800	1100	
$\varepsilon_{11}^T/\varepsilon_0$	1800	3300	–	1400	–	–	1200	1700	
Resistivity ρ	5	1	5	1	1	1	5	5	10^{10} Ωm
Time constant $\rho\varepsilon_{33}^T$ (25 °C)	>300	>500	>25	>7	–	–	>100	>250	minute
Dielectric loss factor tan δ	20	16	15	2.5	3.5	2	28	24	10^{-3}
Electro-mechanical data									
Coupling factor									
k_p	0.68	0.70	0.64	0.64	0.61	0.53	0.59	0.63	
k_{33}	0.75	0.80	0.74	0.74	0.70	0.66	0.70	0.73	
k_{31}	0.38	0.39	0.37	0.38	0.34	0.30	0.36	0.37	
k_{15}	0.66	–	–	0.70	–	–	0.66	0.68	
Piezoelectric charge constants									
d_{33}	460	700	450	325	315	230	260	340	10^{-12} C/N or m/V
d_{31}	–200	–280	–200	–150	–130	–100	–120	–150	10^{-12} C/N or m/V
d_{15}	515	–	–	480	–	–	400	500	10^{-12} C/N or m/V
Piezoelectric voltage constants									
g_{33}	24	20	25	30	27	27	36	30	10^{-3} Vm/N or m^2/C
g_{31}	–10	–10	–12	–12	–11	–11	–12	–10	10^{-3} Vm/N or m^2/C
g_{15}	33	–	–	39	–	–	38	33	10^{-3} Vm/N or m^2/C
Time stability									
Coupling factor k_p	–0.5	–0.6	–1.5	–1.5	–2.5	–2.0	–0.5	–0.5	relative change per time decade (%)
Permittivity ε_{33}^T	–1.0	–1.0	–2.0	1.0	–6.0	–4.5	–0.5	–0.5	
Frequency constant N_p^E	0.5	0.3	0.5	0.5	1.5	1.0	0.5	0.5	
Quality factor Q_m^E	–	–3.0	–	10.0	–	–	–	–	
Dielectric loss factor tan δ	–	–	–	–10	–	–	–	–	

Material grade specification PXE 5

SYMBOL	TYPICAL VALUE	UNIT
d_{33}	460	10^{-12} m/V
d_{31}	–200	10^{-12} m/V
g_{33}	24	10^{-3} Vm/N
g_{31}	–10	10^{-3} Vm/N
k_p	0.68	–
$\varepsilon_{33}^{T}/\varepsilon_0$	2100	–
N_P^E	1975	Hzm
s_{33}^E	18	10^{-12}/Pa
T_c	285	°C

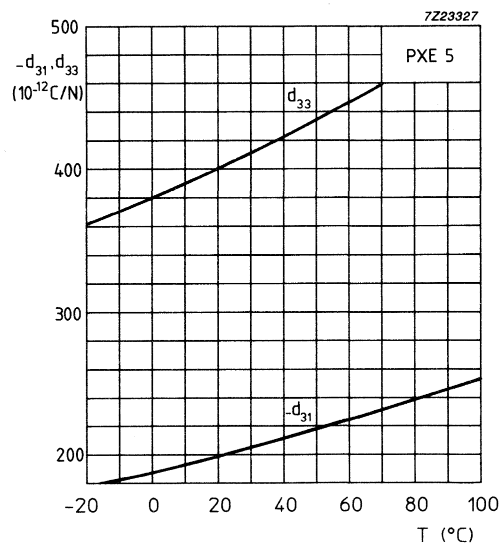


Fig.1 Charge constants as a function of temperature.

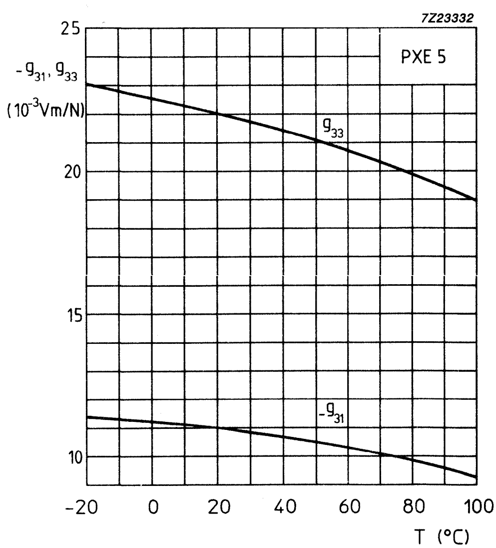


Fig.2 Voltage constants as a function of temperature.

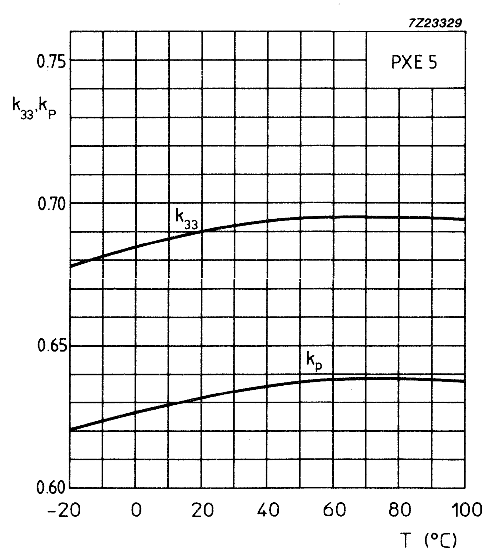


Fig.3 Coupling factors as a function of temperature.

Material grade specification

PXE 5

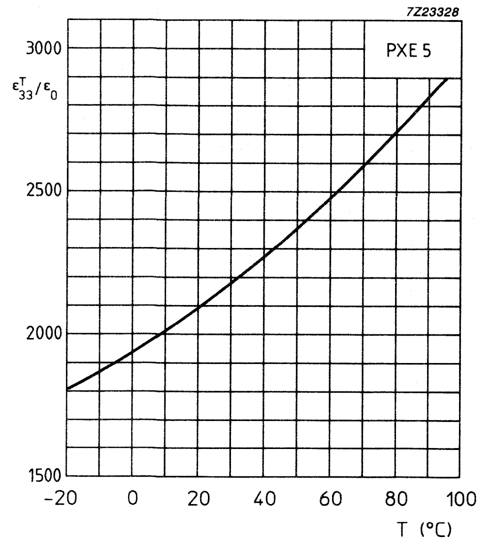


Fig.4 Dielectric constant as a function of temperature.

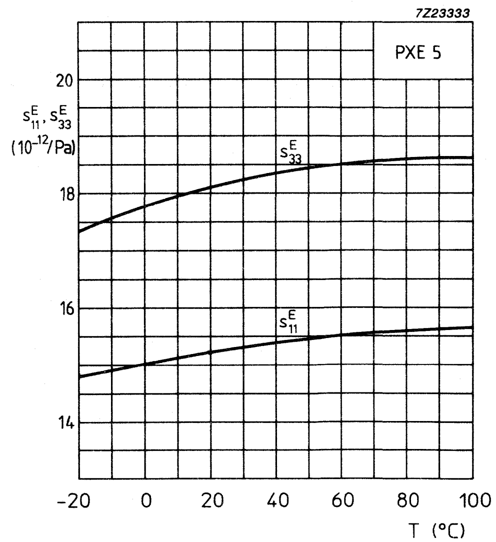


Fig.5 Compliances as a function of temperature.

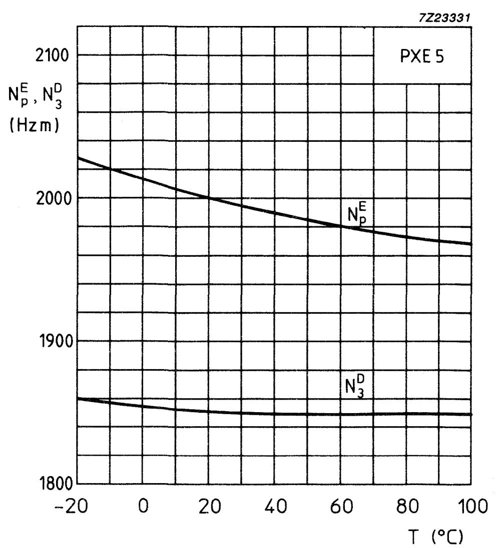


Fig.6 Frequency constants as a function of temperature.

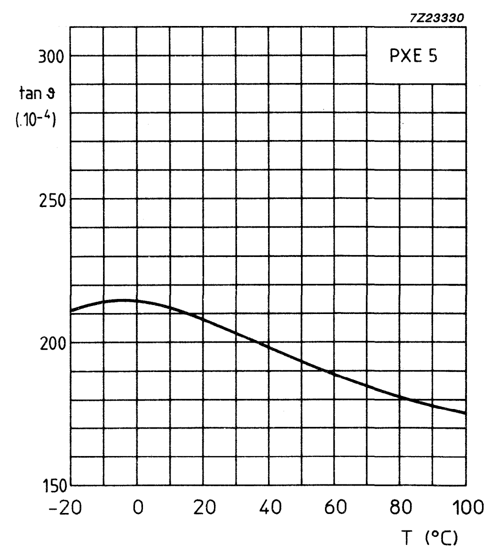


Fig.7 Dielectric loss factor as a function of temperature.

Material grade specification PXE 21

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	–
$\varepsilon_{33}^{T}/\varepsilon_0$	2000	–
N_P^E	2000	Hzm
s_{33}^E	19	10^{-12}/Pa
T_c	270	°C

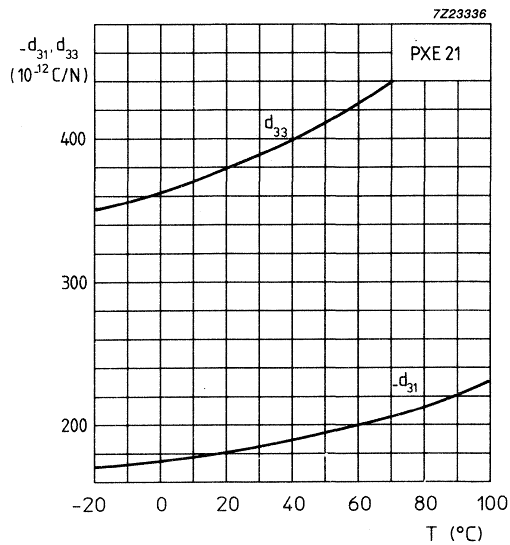


Fig.1 Charge constants as a function of temperature.

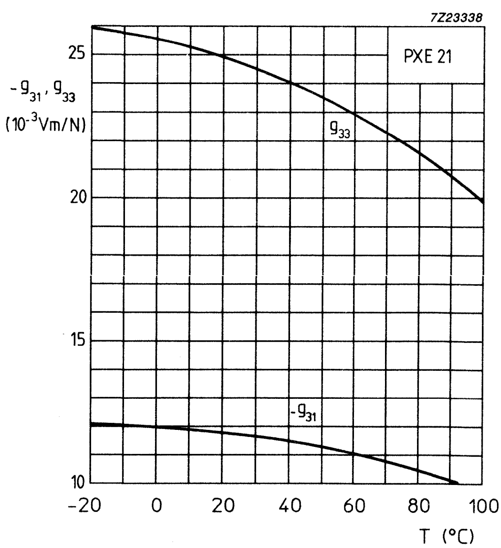


Fig.2 Voltage constants as a function of temperature.

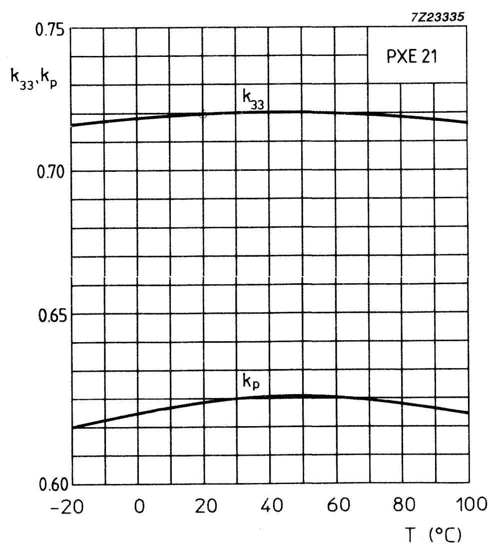


Fig.3 Coupling factors as a function of temperature.

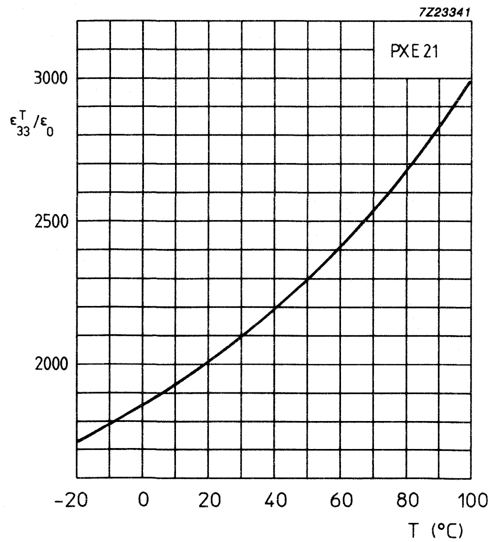


Fig.4 Dielectric constant as a function of temperature.

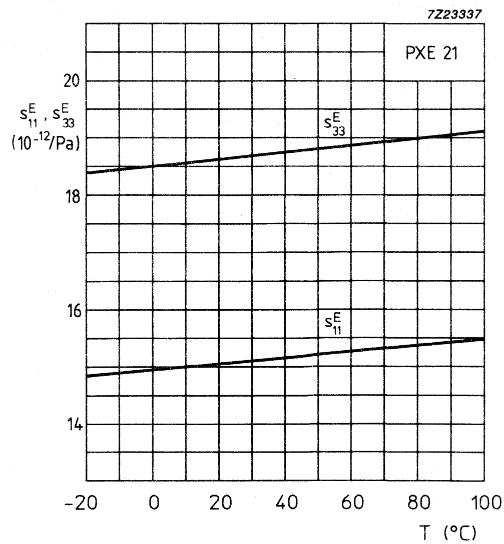


Fig.5 Compliances as a function of temperature.

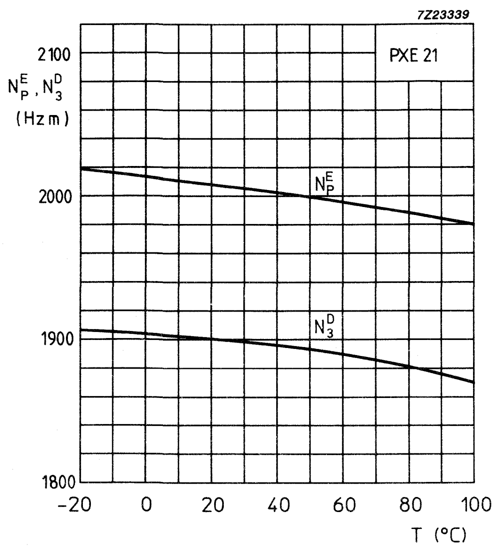


Fig.6 Frequency constants as a function of temperature.

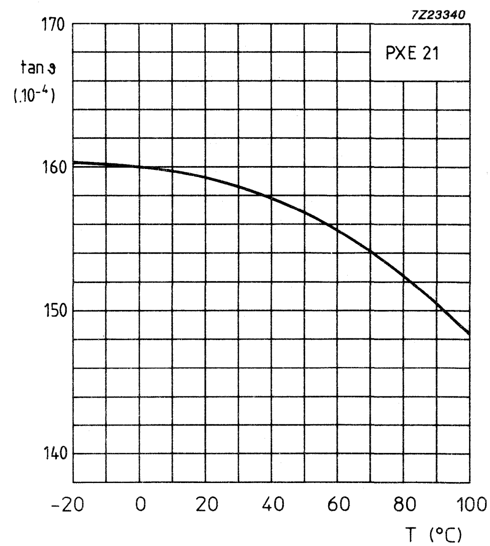


Fig.7 Dielectric loss factor as a function of temperature.

Material grade specification

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	–
$\varepsilon_{33}^{T}/\varepsilon_0$	1225	–
N_P^E	2175	Hzm
s_{33}^E	15	10^{-12}/Pa
T_c	315	°C

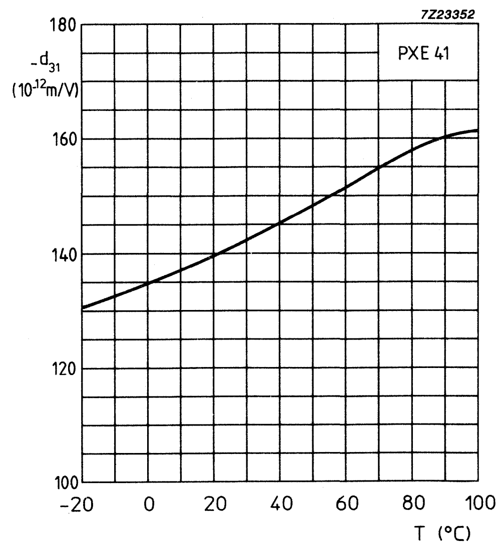


Fig.1 Charge constant as a function of temperature.

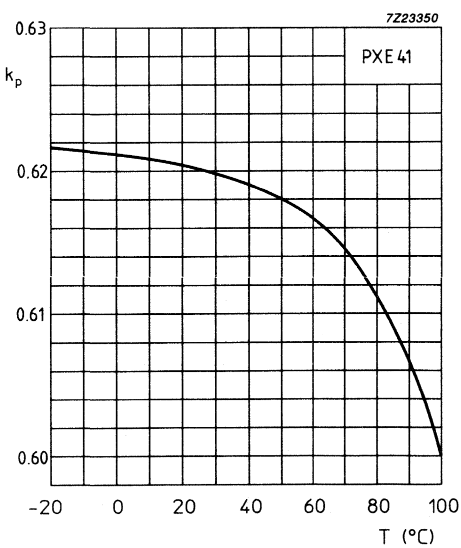


Fig.2 Coupling factor as a function of temperature.

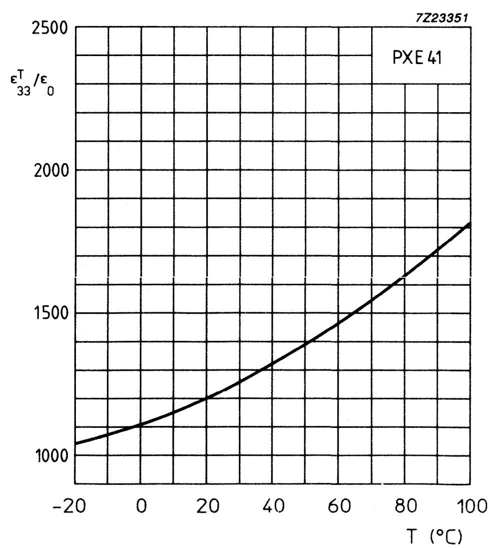


Fig.3 Dielectric constant as a function of temperature.

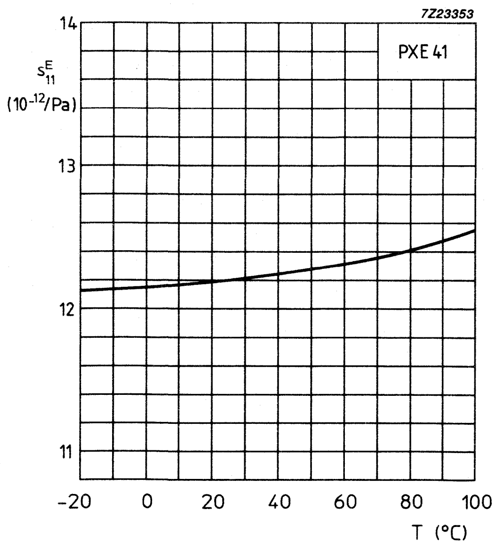


Fig.4 Compliance as a function of temperature.

Material grade specification PXE 42

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	–
$\varepsilon^T_{33}/\varepsilon_0$	1325	–
N^E_P	2200	Hzm
s^E_{33}	15	10^{-12}/Pa
T_c	325	°C

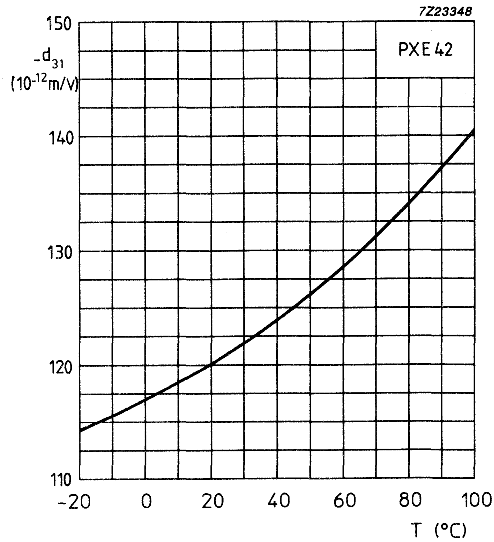


Fig.1 Charge constant as a function of temperature.

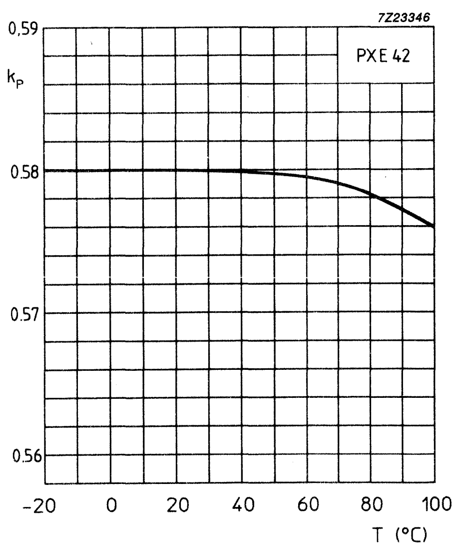


Fig.2 Coupling factor as a function of temperature.

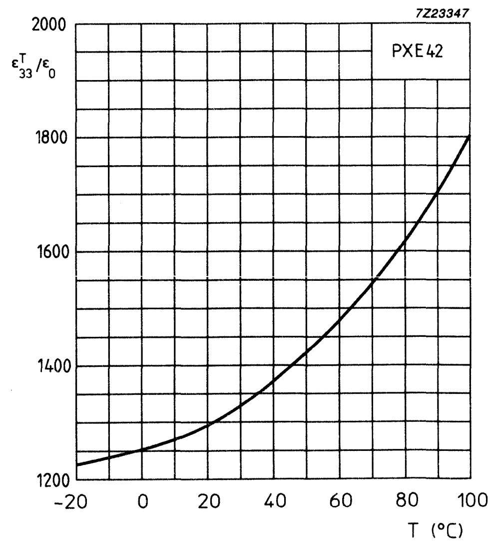


Fig.3 Dielectric constant as a function of temperature.

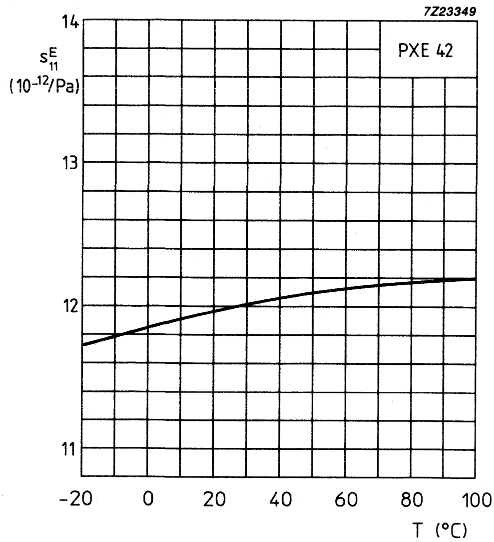


Fig.4 Compliance as a function of temperature.

Material grade specification PXE 43

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	–
$\varepsilon_{33}^{T}/\varepsilon_0$	950	–
N_P^E	2350	Hzm
s_{33}^E	13	10^{-12}/Pa
T_c	300	°C

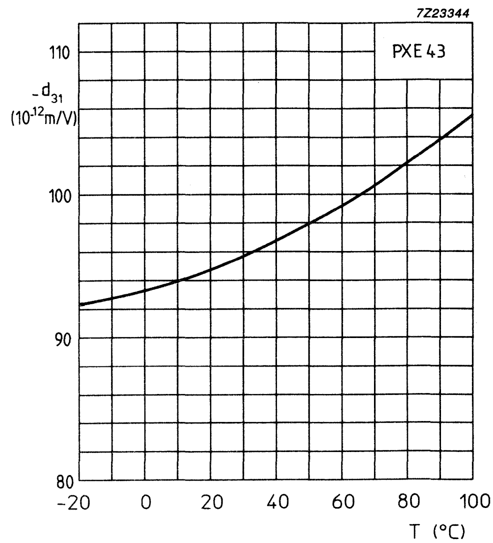


Fig.1 Charge constant as a function of temperature.

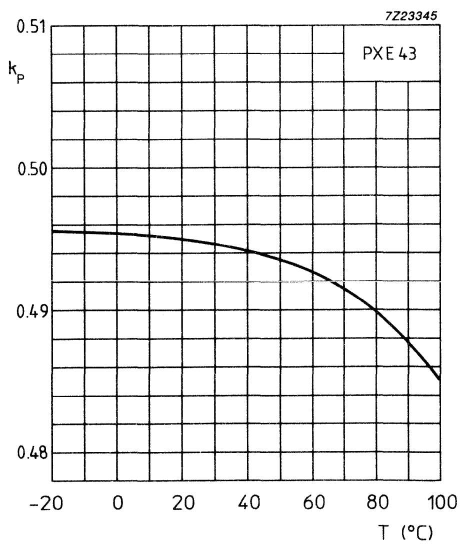


Fig.2 Coupling factor as a function of temperature.

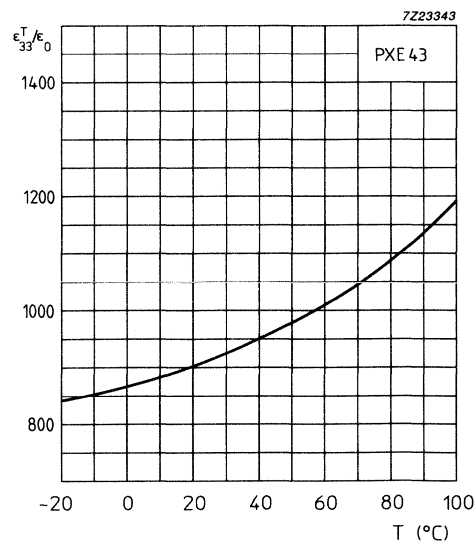


Fig.3 Dielectric constant as a function of temperature.

Material grade specification PXE 43

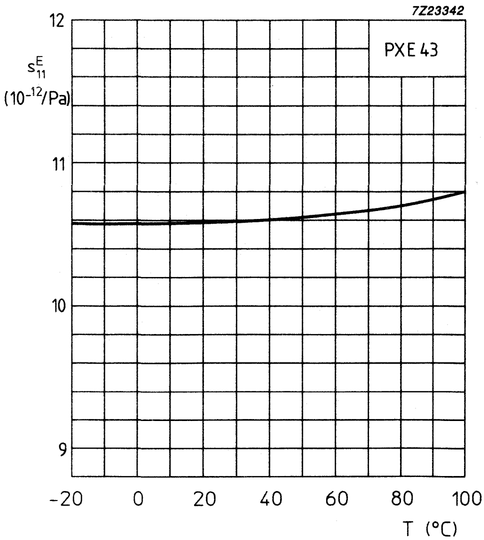


Fig.4 Compliance as a function of temperature.

Material grade specification PXE 52

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	–
$\varepsilon_{33}^{T}/\varepsilon_0$	3900	–
N_P^E	1925	Hzm
s_{33}^E	20	10^{-12}/Pa
T_c	165	°C

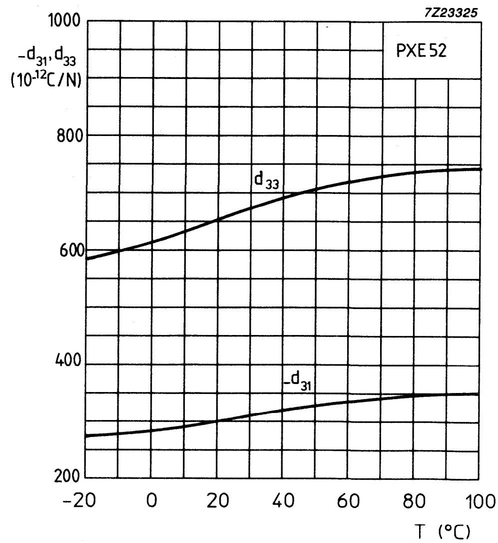


Fig.1 Charge constants as a function of temperature.

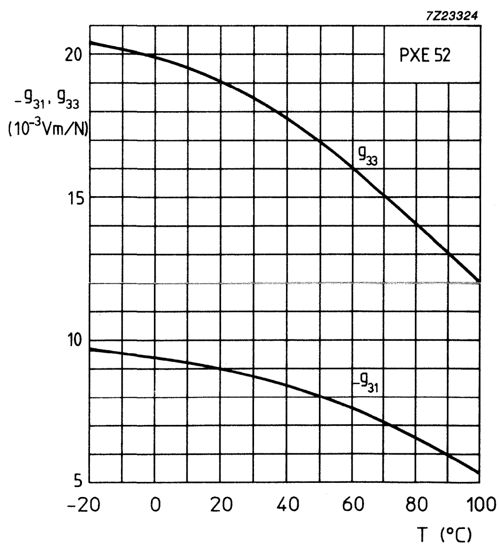


Fig.2 Voltage constants as a function of temperature.

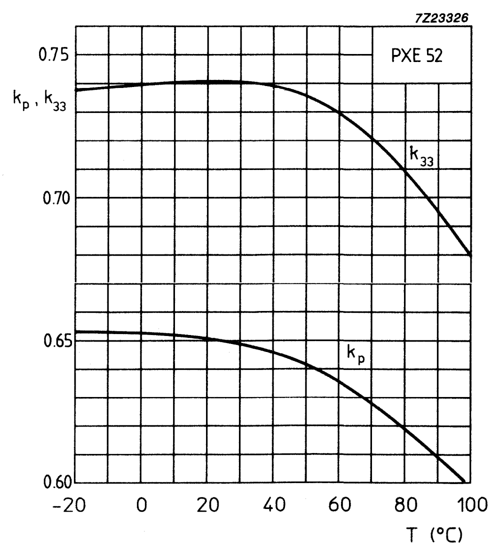


Fig.3 Coupling factors as a function of temperature.

Material grade specification PXE 52

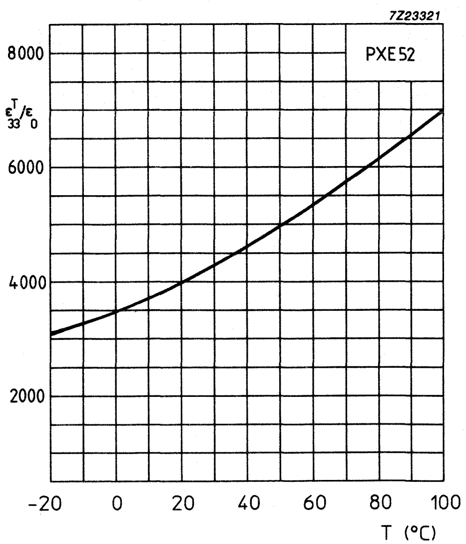


Fig.4 Dielectric constant as a function of temperature.

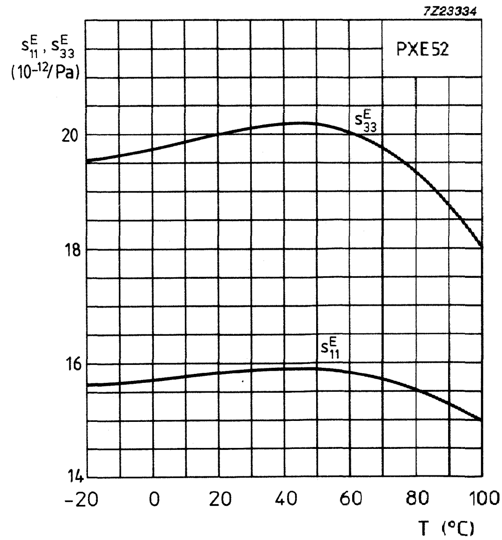


Fig.5 Compliances as a function of temperature.

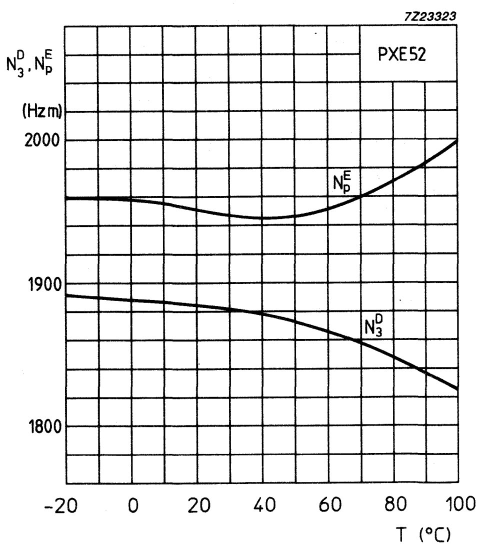


Fig.6 Frequency constants as a function of temperature.

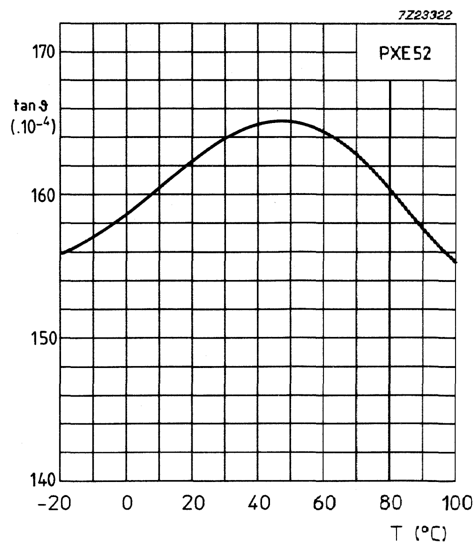
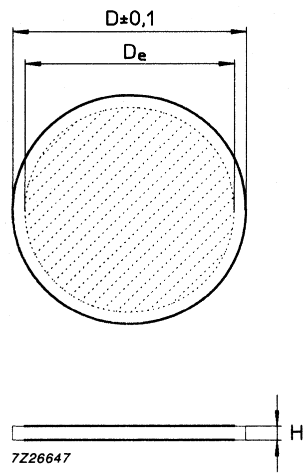


Fig.7 Dielectric loss factor as a function of temperature.

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.



Dimensions in mm.

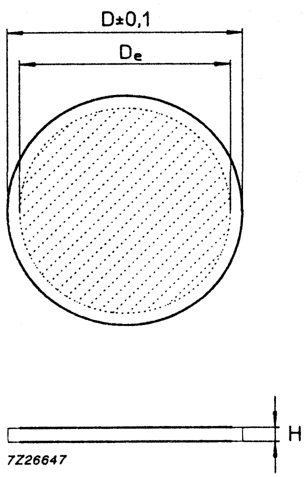
Fig.1 Disc with nickel electrode.

Electrode material: nickel

GRADE	D (mm)	D_e (mm)	H (mm)	CAPACITANCE (pF)	ORDERING CODE
PXE 5	5	5.0 ±0.1	0.3 ±0.03	1220 ±25%	4322 020 1750
	5	5.0 ±0.1	0.5 ±0.03	750 ±25%	4322 020 1751
	5	5.0 ±0.1	1.0 ±0.03	375 ±25%	4322 020 1752
	5	5.0 ±0.1	2.0 ±0.1	185 ±25%	4322 020 1753
	10	9.0 ±0.25	0.2 ±0.03	6500 ±25%	4322 020 1754
	10	9.0 ±0.25	0.5 ±0.03	2650 ±25%	4322 020 1755
	10	9.5 ±0.25	1.0 ±0.03	1320 ±25%	4322 020 1756
	10	9.5 ±0.25	2.0 ±0.1	660 ±25%	4322 020 1757
	10	9.5 ±0.25	3.0 ±0.1	440 ±25%	4322 020 1758
	10	9.5 ±0.25	5.0 ±0.1	260 ±25%	4322 020 1759
	16	15.0 ±0.25	0.2 ±0.03	17 650 ±25%	4322 020 1760
	16	15.0 ±0.25	0.5 ±0.03	7150 ±25%	4322 020 1761
	16	15.5 ±0.25	1.0 ±0.03	3575 ±25%	4322 020 1762
	16	15.5 ±0.25	2.0 ±0.1	1790 ±25%	4322 020 1763
	16	15.5 ±0.25	3.0 ±0.1	1185 ±25%	4322 020 1764

Electrode material: nickel

GRADE	D (mm)	D_e (mm)	H (mm)	CAPACITANCE (pF)	ORDERING CODE
PXE 5	20	19.0 ±0.25	0.2 ±0.03	28 100 ±25%	4322 020 1765
	20	19.0 ±0.25	0.5 ±0.03	11 400 ±25%	4322 020 1766
	20	19.5 ±0.25	1.0 ±0.03	5700 ±25%	4322 020 1767
	20	19.5 ±0.25	2.0 ±0.1	2850 ±25%	4322 020 1768
	25	24.0 ±0.25	0.2 ±0.03	44 550 ±25%	4322 020 1769
	25	24.0 ±0.25	0.5 ±0.03	18 000 ±25%	4322 020 1770
	25	24.5 ±0.25	1.0 ±0.03	9000 ±25%	4322 020 1771
	25	24.5 ±0.25	2.0 ±0.1	4500 ±25%	4322 020 1772



Dimensions in mm.

Fig.2 Disc with silver electrode.

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.

Electrode material: silver

GRADE	D (mm)	D_e (mm)	H (mm)	CAPACITANCE (pF)	ORDERING CODE
PXE 5	5	=D	0.3 ±0.03	1220 ±25%	4322 020 1787
	5	=D	0.5 ±0.03	750 ±25%	4322 020 1788
	5	=D	1.0 ±0.03	375 ±25%	4322 020 1789
	5	=D	2.0 ±0.1	185 ±25%	4322 020 1790
	10	9 ±0.25	0.5 ±0.03	2650 ±25%	4322 020 1791
	10	=D	1.0 ±0.03	1320 ±25%	4322 020 0233
	10	=D	2.0 ±0.1	660 ±25%	4322 020 1792
	10	=D	3.0 ±0.1	440 ±25%	4322 020 0536
	10	=D	5.0 ±0.1	260 ±25%	4322 020 0537
	16	15 ±0.25	0.5 ±0.03	7150 ±25%	4322 020 1793
	16	=D	1.0 ±0.03	3575 ±25%	4322 020 0225
	25	24 ±0.25	0.5 ±0.03	18 000 ±25%	4322 020 1785
	25	=D	1.0 ±0.03	9000 ±25%	4322 020 1741
	25	=D	2.0 ±0.1	4500 ±25%	4322 020 1786

Electrode material: silver

GRADE	D (mm)	H (mm)	CAPACITANCE (pF)	ORDERING CODE
PXE 41	31.75 ±0.5	≈14.3 (note 1)	620 ±25%	4322 020 0524
	25.4 ±0.5	≈10.2 (note 2)	520 ±25%	4322 020 0575
PXE 42	25 ±0.1	1 ±0.1	5750 ±25%	4322 020 1744
	25 ±0.1	2 ±0.1	2870 ±25%	4322 020 1745
	38 ±0.6	3 ±0.1	4400 ±25%	4322 020 1746
	38 ±0.6	6 ±0.1	2100 ±25%	4322 020 1747
	50 ±1.0	3 ±0.1	7650 ±25%	4322 020 1748
	50 ±1.0	6 ±0.1	3830 ±25%	4322 020 1749

Notes

Other sizes and material grades are available on request.

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

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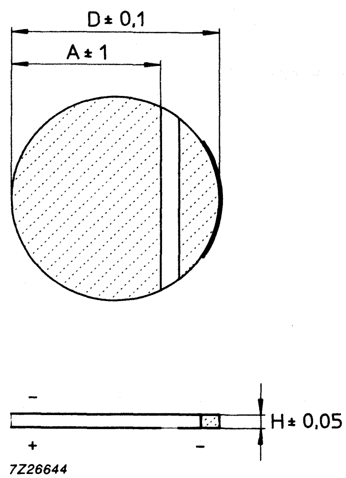


Dimensions in mm.

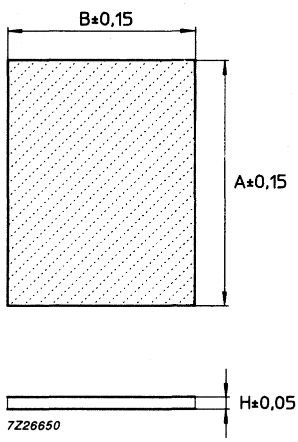
Fig.3 Disc with wrap-around electrode.

DISCS WITH WRAP-AROUND ELECTRODE

These discs have provision for connecting both electrodes from one side by means of a wrap-round 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.

Electrode material: silver

GRADE	D (mm)	A (mm)	H (mm)	CAPACITANCE (pF)	ORDERING CODE
PXE 5	16	10.0	1	2600 ±25%	4322 020 0227
	10	6.5	1	1000 ±25%	4322 020 0842



Dimensions in mm.

Fig.1 Plate.

SQUARE AND RECTANGULAR PLATES

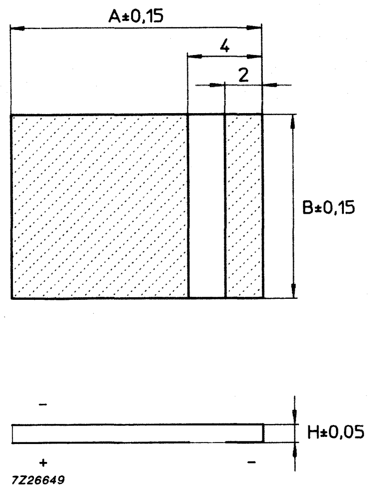
The material grade in the following two tables is PXE 5, but other grades and sizes are available on request (any thickness between 0.2 and 3.0 mm is possible). The positive pole is marked.

Electrode material: nickel

GRADE	A (mm)	B (mm)	H (mm)	CAPACITANCE (pF)	ORDERING CODE
PXE 5	4	4	0.3	990 ±20%	4322 020 1350
	8	4	0.3	1980 ±20%	4322 020 1352
	12	4	0.3	2970 ±20%	4322 020 1354
	6	6	0.3	2230 ±20%	4322 020 1355
	12	6	0.3	4460 ±20%	4322 020 1358
	8	8	0.3	3960 ±20%	4322 020 1359
	10	10	0.3	6200 ±20%	4322 020 1362
	12	12	0.3	8920 ±20%	4322 020 1364
	12	6	0.5	2670 ±20%	4322 020 1365
	12	6	1.0	1340 ±20%	4322 020 1366

Electrode material: silver

GRADE	A (mm)	B (mm)	H (mm)	CAPACITANCE (pF)	ORDERING CODE
PXE 5	16	12	1	3500 ±20%	4322 020 0231
	12	6	0.5	2670 ±20%	4322 020 0705
	12	6	1	1340 ±20%	4322 020 0706
	12	6	1.25	1070 ±20%	4322 020 0729



Dimensions in mm.

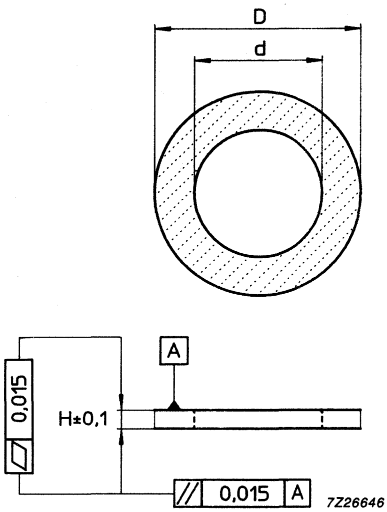
Fig.2 Plate with wrap-around electrode.

PLATES WITH WRAP-AROUND ELECTRODES

These plates have provision for connecting both electrodes from one side by means of a wrap-round 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.

Electrode material: silver

GRADE	A (mm)	B (mm)	H (mm)	CAPACITANCE (pF)	ORDERING CODE
PXE 5	10	4	1	480 ±25%	4322 020 1368
	10	4	2	240 ±25%	4322 020 1369
	10	5	1	600 ±25%	4322 020 1370
	10	5	2	300 ±25%	4322 020 1371
	15	5	2	550 ±25%	4322 020 1372



Dimensions in mm.

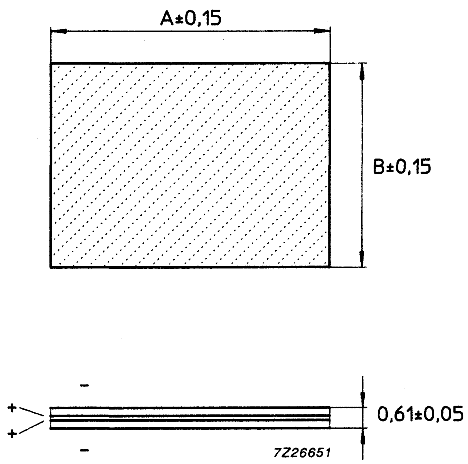
Fig.1 Ring.

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.

GRADE	D (mm)	d (mm)	H (mm)	CAPACITANCE (pF)	ORDERING CODE
PXE 5	10 ±0.1	5.0 ±0.1	2	550 ±25%	4322 020 0657
	12 ±0.1	6.0 ±0.1	1	1365 ±25%	4322 020 0642
	12 ±0.1	6.0 ±0.1	1.5	910 ±25%	4322 020 0665
PXE 42	10 ±0.1	5.0 ±0.1	2	340 ±25%	4322 020 0666
	15 ±0.1	6.0 ±0.1	3	580 ±25%	4322 020 0647
	15 ±0.1	8.0 ±0.1	2	740 ±25%	4322 020 0667
	20 ±0.4	6.0 ±0.1	5	650 ±25%	4322 020 0613
	25 ±0.5	10.0 ±0.2	4	1200 ±25%	4322 020 0668
	25 ±0.5	10.0 ±0.2	5	965 ±25%	4322 020 0669
	25 ±0.5	10.0 ±0.2	6	800 ±25%	4322 020 0670
	38 ±0.6	12.7 ±0.3	4	2970 ±25%	4322 020 0609
	38 ±0.6	12.7 ±0.3	6	1970 ±25%	4322 020 0671
	38 ±0.6	12.7 ±0.3	6.35	1870 ±25%	4322 020 0604
	38 ±0.6	19.0 ±0.4	4	2970 ±25%	4322 020 0672
	38 ±0.6	19.0 ±0.4	6.35	1575 ±25%	4322 020 0607
	50 ±1.0	20.0 ±0.4	5	3865 ±25%	4322 020 0673
	50 ±1.0	20.0 ±0.4	6	3200 ±25%	4322 020 0674
	50 ±1.0	20.0 ±0.4	6.35	3040 ±25%	–

GRADE	D (mm)	d (mm)	H (mm)	CAPACITANCE (pF)	ORDERING CODE
PXE 43	10 ±0.1	5.0 ±0.1	2	245 ±25%	4322 020 0659
	15 ±0.1	8.0 ±0.1	2	530 ±25%	4322 020 0660
	20 ±0.4	6.0 ±0.1	5	480 ±25%	4322 020 0629
	25 ±0.5	10.0 ±0.2	4	870 ±25%	4322 020 0661
	25 ±0.5	10.0 ±0.2	5	690 ±25%	4322 020 0628
	25 ±0.5	10.0 ±0.2	6	575 ±25%	4322 020 0662
	38 ±0.6	12.7 ±0.3	4	2130 ±25%	4322 020 0663
	38 ±0.6	12.7 ±0.3	6	1410 ±25%	4322 020 0664
	38 ±0.6	12.7 ±0.3	6.35	1340 ±25%	4322 020 0626
	50 ±1.0	20.0 ±0.5	5	2770 ±25%	4322 020 0615
	50 ±1.0	20.0 ±0.5	6	2295 ±25%	4322 020 0614



Dimensions in mm.

Fig.1 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 actuators.

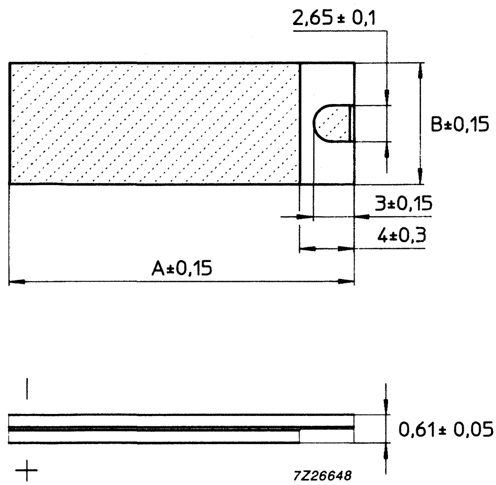
Electrode material: nickel

A (mm)	B (mm)	CAPACITANCE (pF)	ORDERING CODE
4.0	4.0	420 ±20%	4322 020 0457
6.0	4.0	630 ±20%	4322 020 0458
8.0	4.0	840 ±20%	4322 020 0459
10.0	4.0	1050 ±20%	4322 020 0460
12.0	4.0	1250 ±20%	4322 020 0461
6.0	6.0	950 ±20%	4322 020 0462
8.0	6.0	1250 ±20%	4322 020 0463
10.0	6.0	1600 ±20%	4322 020 0464
12.0	6.0	1900 ±20%	4322 020 0465
8.0	8.0	1700 ±20%	4322 020 0466
10.0	8.0	2100 ±20%	4322 020 0467
12.0	8.0	2550 ±20%	4322 020 0468
10.0	10.0	2650 ±20%	4322 020 0469
12.0	10.0	3150 ±20%	4322 020 0470
12.0	12.0	3800 ±20%	4322 020 0471

A (mm)	B (mm)	CAPACITANCE (pF)	ORDERING CODE
12.7	1.6	600 ±20%	4322 020 0825
15.5	1.6	740 ±20%	4322 020 0824
70.0	1.6	3300 ±20%	4322 020 0823

Note

Other sizes are available on request.



Dimensions in mm.

Fig.1 Parallel bimorph.

PARALLEL BIMORPH ELEMENTS

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

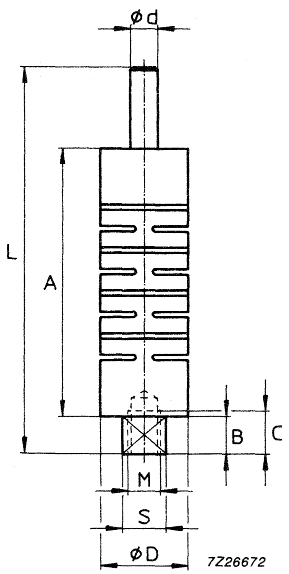
Electrode material: nickel

A (mm)	B (mm)	CAPACITANCE (pF)	f_r min. (Hz)	DEFLECTION (μm) (note 1)	ORDERING CODE
15	6	9000	2200	95 ±20%	4322 020 1453
20	6	13 000	1000	225 ±20%	4322 020 1454
25	6	16 500	500	400 ±20%	4322 020 1455
30	6	20 000	350	640 ±20%	4322 020 1456
35	6	24 000	240	935 ±20%	4322 020 1457
15	12	18 000	2200	95 ±20%	4322 020 1458
20	12	25 000	1000	225 ±20%	4322 020 1459
25	12	33 000	500	500 ±20%	4322 020 1460
30	12	40 000	350	640 ±20%	4322 020 1461
35	12	48 000	240	935 ±20%	4322 020 1462

Notes

Other sizes are available on request.

1. Deflection peak-to-peak at 300 V peak-to-peak (±150 V) with free length = A–5 mm.



Dimensions in mm.

Fig.1 High-power actuator.

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 a pile of PXE discs, held in compression with a force of approximately 1000 N by a cylindrical steel spring and interleaved with copper foil electrodes. 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 µs.

TYPE	HPA 1	HPA 2	HPA 3	UNIT
ORDERING CODE	4322 020 1905	4322 020 1906	4322 020 1907	
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	32 ±0.1	mm
M	M 6 x 0.75	M 8 x 1	M 12 x 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

SPECIALTY FERRITES

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 therefore most suitable for frequencies over 1 MHz but MnZn ferrites exhibit higher permeabilities (μ_i) and saturation induction levels (B_s).

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

Ferrite parts can be 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 real ferrite properties.

Another method is to grow single crystals from a melt which is done for our grade 8X1. Many special customized products are only needed in small numbers. The most economical way is to grind them from solid blocks. These blocks are produced by pressing and sintering. Grinding requires diamond coated saws, profiled wheels and drills. Very narrow tolerances can be achieved. To improve surface quality a polishing operation can be used to get a mirror-like finish.

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 need a very stringent control in conditions.

Magnetism in ferrites

A sintered ferrite consists of small crystals, typically 10 - 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.1.

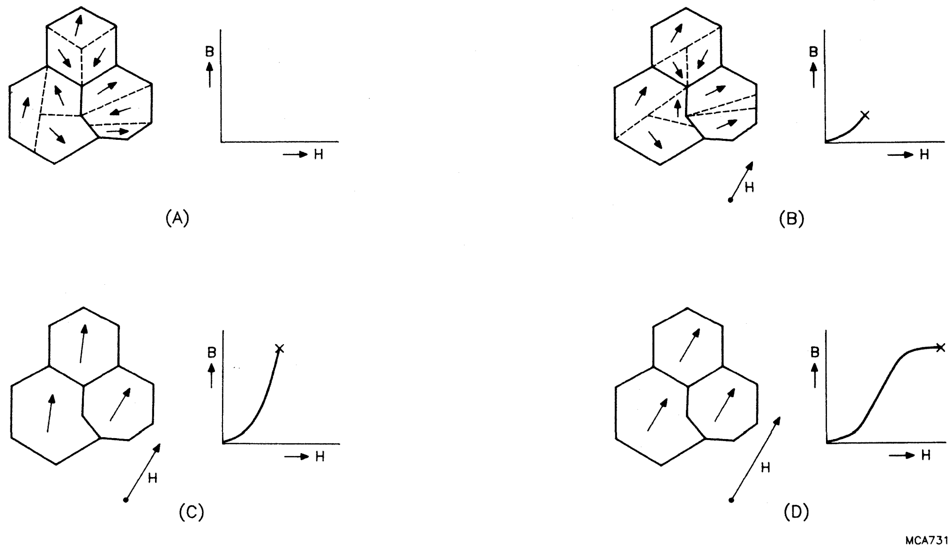


Fig.1 Alignment of domains.

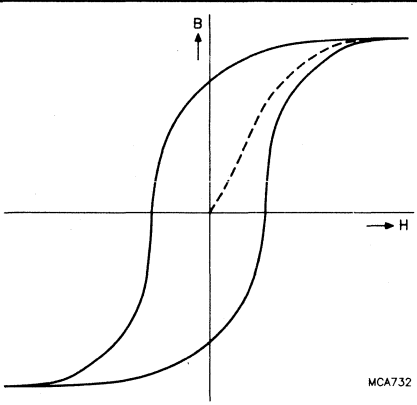


Fig.2 Hysteresis loop.

During this magnetization process energy barriers have to be overcome. Therefore the magnetization will always lag behind the field. A so-called hysteresis loop (Fig.2) 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. Also the shape of the hysteresis loop has a marked influence on other properties, for example, power losses.

EXPLANATION OF TERMS and FORMULAE

Symbols and units

SYMBOL	UNIT	DESCRIPTION
A_e	mm^2	effective cross-sectional area of a core
A_{min}	mm^2	minimum cross-sectional area of a core
A_L	nH	inductance factor
B	T	magnetic flux density
B_r	T	remanence
B_s	T	saturation flux density
$\hat{B}$	T	peak flux density
C	F	capacitance
D_F	–	disaccommodation factor
f	Hz	frequency
G	µm	gap length
H	A/m	magnetic field strength
H_c	A/m	coercivity
$\hat{H}$	A/m	peak magnetic field strength
I	A	current
l_e	mm	effective magnetic path length
L	H	inductance
N	–	number of turns
P_v	mW/cm^3	specific power loss of core material
Q	–	quality factor
T_c	°C	Curie temperature
V_e	mm^3	effective volume of a core
α_F	K^{-1}	temperature factor of permeability
$\tan \delta/\mu_i$	–	loss factor
η_B	T^{-1}	hysteresis magnetic constant
μ	–	absolute permeability
μ_o	Hm^{-1}	magnetic constant ($4\pi \cdot 10^{-7}$)
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	Ωm	resistivity
$\Sigma(l/A)$	mm^{-1}	core factor (C1)

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.

$B = \mu_o H + J$, or
$B = \mu_o (H + M)$

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

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

$$\frac{B}{H} = \mu_o\left(1 + \frac{M}{H}\right) = \mu_{absolute}$$

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

$$\frac{B}{H} = \mu_o \mu_r$$

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 (μ_i)

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

$$\mu_i = \frac{1}{\mu_o} \cdot \frac{\Delta B}{\Delta H} (\Delta H \cdot 0)$$

Initial permeability is dependent on temperature and frequency.

EFFECTIVE PERMEABILITY (μ_e)

If an airgap 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 (μ_i) of the soft magnetic material and the dimensions of airgap and circuit.

$$\mu_e = \frac{\mu_i}{1 + (G/l_e \cdot \mu_i)}$$

where G is the gap length
l_e is the effective length of magnetic circuit.

AMPLITUDE PERMEABILITY (μ_a)

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

$$\mu_a = \frac{1}{\mu_o} \cdot \frac{\hat{B}}{\hat{H}}$$

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

INCREMENTAL PERMEABILITY (μ_Δ)

The permeability observed when an alternating magnetic field is superimposed on a static bias field H_{DC} is called the incremental permeability.

$$\mu_\Delta = \frac{1}{\mu_o} \left[\frac{\Delta B}{\Delta H} \right] H_{DC}$$

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

COMPLEX PERMEABILITY (μ)

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

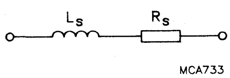


Fig.3 Series representation.

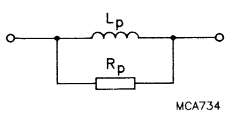


Fig.4 Parallel representation.

For series representation,

$$\bar{Z} = j\omega L_s + R_s$$

and for parallel representation,

$$\bar{Z} = \frac{1}{1/j\omega L_p + 1/R_p}$$

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

$$\mu = \mu_s' - j\mu_s'' \text{ or}$$

$$\frac{1}{\bar{\mu}} = \frac{1}{\mu_p'} - \frac{1}{\mu_p''}$$

The phase shift caused by magnetic losses is given by:

$$\tan \delta_m = \frac{R_s}{\omega L_s} = \frac{\mu_s''}{\mu_s'} \quad \textit{or}$$

$$\tan \delta_m = \frac{\omega L_p}{R_p} = \frac{\mu_p'}{\mu_p''}$$

For calculations on inductors and also to characterise ferrites, the series representation 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:

$$\mu_p' = \mu_s' \ (1 + \tan^2 \delta)$$

$$\mu_p'' = \mu_s'' \ (1 + \frac{1}{\tan^2 \delta})$$

Loss factor ($\tan \delta / \mu_i$)

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

- hysteresis losses
- Eddy current losses
- residual losses.

This gives the formula:

$$\tan \delta_m = \tan \delta_h + \tan \delta_F + \tan \delta_r$$

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

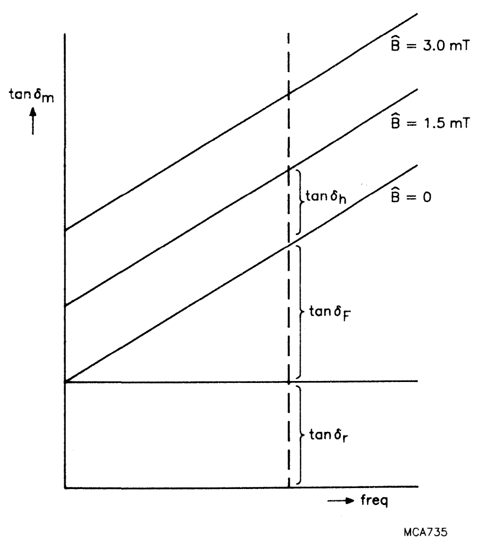


Fig.5 Magnetic losses ($\tan \delta_m$) as a function of frequency.

Hysteresis losses vanish for very low field strength. 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:

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

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

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

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

$$(\tan \delta_m)_{gapped} = \frac{\tan \delta_m}{\mu_i} \bullet \mu_e$$

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

$$(\tan \delta)_{gapped} = \frac{\tan \delta}{\mu_i} \bullet \mu_e$$

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:

$$Q = \frac{1}{\tan \delta} = \frac{\omega L}{R_{tot}} = \frac{reactance}{total\ resistance}$$

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

HYSTERESIS MATERIAL CONSTANT (η_B)

If 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:

$$\eta_B = \frac{\Delta \tan \delta_m}{\mu_e \bullet \Delta \hat{B}}$$

The hysteresis loss factor for a certain flux can be calculated using η_B.

$$\frac{\tan \delta_h}{\mu_e} = \eta_B \bullet B$$

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

EFFECTIVE CORE DIMENSIONS ($\Sigma(l/A)$, A_e, l_e, V_e)

To facilitate calculations on non-uniform soft magnetic cores, a set of effective dimensions is given on each data sheet. These dimensions, namely 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 reactance of the ideal ring core would be:

$$\frac{l_e}{\mu \bullet A_e}$$

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

$$\frac{1}{\mu_e} \bullet \Sigma\frac{l}{A}$$

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

$$L = \frac{\mu_o N^2}{\frac{1}{\mu_e} \bullet \Sigma\frac{l}{A}}$$

$$= \frac{1.257 \bullet 10^{-9} N^2}{\frac{1}{\mu_e} \bullet \Sigma\frac{l}{A}} \ (in\ H)$$

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

for sine wave:

$$\hat{B} = \frac{U \sqrt{2} \bullet 10^9}{\omega\ A_e\ N} \ (in\ mT)$$

$$= \frac{2.25 U \bullet 10^8}{f\ N\ A_e} \ (in\ mT)$$

for square wave:

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

where:

A_e is the effective area in mm^2
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 l_e:

$$\hat{H} = \frac{I\ N \sqrt{2}}{l_e} \ (A/m)$$

If the cross-sectional area of a core is non-uniform, there will always be a point where the real cross-section is minimum. 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. The inductance of the core is defined as:

$L = N^2 A_L$

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

$$A_L = \frac{\mu_o \ \mu_e \bullet 10^6}{\Sigma \frac{l}{A}}$$

$$= \frac{1.257\mu_e}{\Sigma \frac{l}{A}} (nH)$$

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 is the remanent flux density (B_r). This remanent flux returns to zero for a certain negative field strength which is referred to as coercivity (H_c). These points are clearly shown in Fig.6.

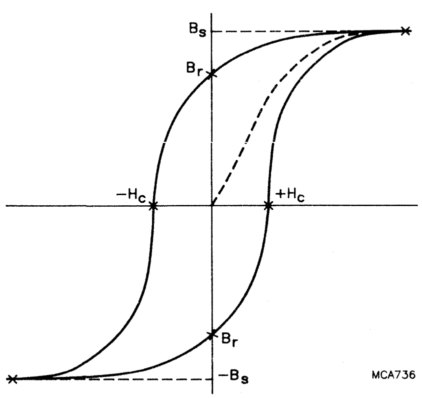


Fig.6 Typical BH curve showing points B_s, B_r and H_c.

TEMPERATURE DEPENDENCY OF THE PERMEABILITY (T_c, α_F)

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 a LC filter with an excellent temperature stability.

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

$$TC = \frac{(\mu_i)_{T2} - (\mu_i)_{T1}}{(\mu_i)_{T1}} \bullet \frac{1}{T_2 - T_1}$$

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

$$TC_{gapped} = \frac{\mu_e}{(\mu_i)_{T1}} \bullet \frac{(\mu_i)_{T2} - (\mu_i)_{T1}}{(\mu_i)^2{}_{T1}} \bullet \frac{1}{T_2 - T_1} = \mu_e \, \alpha_F$$

so

$$\alpha_F = \frac{(\mu_i)_{T2} - (\mu_i)_{T1}}{(\mu_i)^2{}_{T1}} \bullet \frac{1}{T_2 - T_1}$$

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

$$\alpha_F = \frac{(\mu_i)_{T2} - (\mu_i)_{T1}}{(\mu_i)_{T1} \ (\mu_i)_{T2}} \bullet \frac{1}{T_2 - T_1}$$

The temperature factors (α_F) 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:

$$D = \frac{\mu_1 - \mu_2}{\mu_1}$$

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

$$d = \frac{\mu_1 - \mu_2}{\mu_1 \log_{10}(t_2/t_1)}$$

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:

$$D_F = \frac{d}{\mu_i} = \frac{\mu_1 - \mu_2}{\mu_1{}^2 \log_{10}(t_2/t_1)}$$

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

$$\frac{L_1 - L_2}{L_1} = \mu_e \, D_F$$

RESISTIVITY (ρ)

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

Since there is an isolating layer between the crystals, the bulk resistivity is much higher: 0.1 - 10 Ωm for MnZn ferrites and 10^4 - 10^6 Ωm for NiZn and LiZn 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 material grades and types.

Table 1 Resistivity as a function of temperature - grade 3C85

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

Table 2 Resistivity as a function of temperature - grade 4C65

TEMPERATURE (°C)	RESISTIVITY (Ωm)
0	≈ $5 \cdot 10^7$
20	≈ 10^7
60	≈ 10^6
100	≈ 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 a function of frequency - MnZn ferrites

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

Table 4 Resistivity as a function of frequency - NiZn ferrites

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

2.2.15 PERMITTIVITY (ε)

The basic permittivity of all ferrites is of the order of 10. This is valid for MnZn and NiZn materials . Also the isolating material on the grain boundaries 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 - 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 - NiZn ferrites

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

ORDERING INFORMATION

The products in this handbook are identified by an 11 digit code number. All physical and technical properties of the product are described by these 11 digits. It is therefore recommended for use on technical drawings and equipment parts lists.

This 11 digit code may also appear on some packing material inside boxes, e.g. on blister packs for P cores and RM cores.

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

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 packing labels, provides full logistic information as well.

The 12th digit is used as packing indicator. Products in standard packing quantities have a last digit ranging from 1 to 6. The current number is a result of developments in the past. For a range of preferred products, smaller packing units are also available for sampling and design-in support. These are identified by a '9' as the 12th digit.

During all stages of the production process, data are collected and documented with reference to a unique batch number. With this batch number it is always possible to trace the results of process steps afterwards. In case of customer complaints the batch number should always be referred to. It is printed on the label of the product packing.

	=11 NC product code
	=production code
BATCH	=batchnumber
ORIG	=country of origin
RPC	=production center
QTY	=quantity
DATE	=production week
TYPE	=product type description
CODENO	=ordering code

QUALITY

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

Our ferrite cores 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 ferrite 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 in accordance with MIL STD 414 and 105D.

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 no longer 'inspected-in', but 'built-in' by continuous improvement.

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

- raw materials
- production process
- finished products.

Delivery quality

Since most special ferrite products are manufactured in small quantities or even as single items, there are no general rules for quality checks on delivery batches. A close contact between customer and supplier is necessary, to establish criteria depending on the application.

ENVIRONMENTAL ASPECTS OF SOFT FERRITES

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

To be more specific, all grades starting with digit 3 are based on the MnZn composition. The main constituents of, for instance, 3C85 are:

Fe_2O_3	71%
MnO	20%
ZnO	9%

Grades starting with digit 4 are based on the NiZn composition. As an example, the main constituents of 4A11 are:

Fe_2O_3	50%
NiO	24%
ZnO	26%

General warning rules

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

Specialty ferrites

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 ∅25 x ∅15 x 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 material grades

FERRITE GRADE	μ_i at 25 °C (±20%)	B_{sat} at 3000 A/m and 25 °C (typical) (mT)	Tc (°C)	ρ (typical) (Ωm)	FERRITE TYPE	MAIN APPLICATION
3C11	4300	400	≥125	1	MnZn	EMI-suppression and general purpose
3E25	6000	400	≥125	0.5	MnZn	
3E5	10 000	350	≥120	0.5	MnZn	
3C85	2000	500	≥200	2	MnZn	Power conversion
3F3	1800	500	≥200	2	MnZn	
3F4	750	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	350	400	≥260	10^5	NiZn	
8C12	900	250	≥125	10^5	NiZn	
8C11	1200	300	≥125	10^5	NiZn	
2S10	350	250	140	10^5	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	$(90 - 150).10^3$	$(80 - 150).10^3$	N/mm^2
Ultimate compressive strength	200 - 600	200 - 700	N/mm^2
Ultimate tensile strength	20 - 65	30 - 60	N/mm^2
Vickers hardness	600 - 700	800 - 900	N/mm^2
Linear expansion coefficient	$(10 - 12).10^{-6}$	$(7 - 8).10^{-6}$	K^{-1}
Specific heat	700 - 800	750	$J.kg^{-1}.K^{-1}$
Heat conductivity	$(3.5 - 5.0).10^{-3}$	$(3.5 - 5.0).10^{-3}$	$J.mm^{-1}.s^{-1}.K^{-1}$

Material grade specification

2S10

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	≤10 kHz, 0.1 mT, 25 °C	350 ±20%	
ρ	DC, 25 °C	≈10^5	Ωm
T_c		≥135	°C
density		≈4300	kg/m³

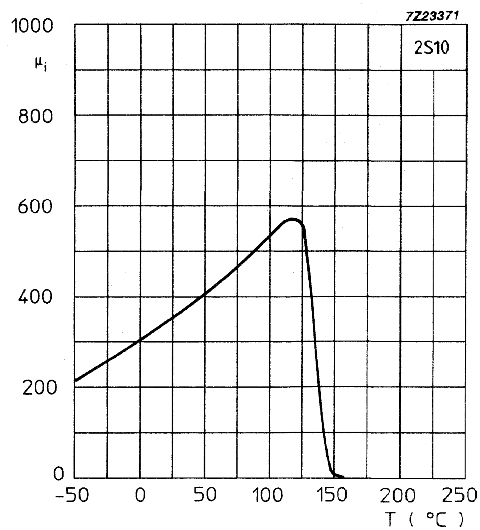


Fig.2 Initial permeability as a function of temperature.

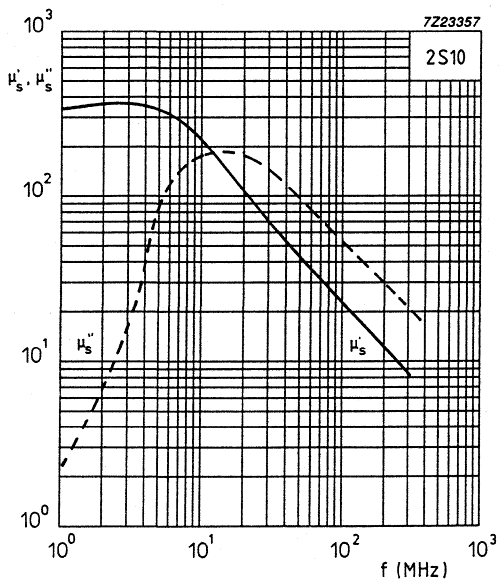


Fig.1 Complex permeability as a function of frequency.

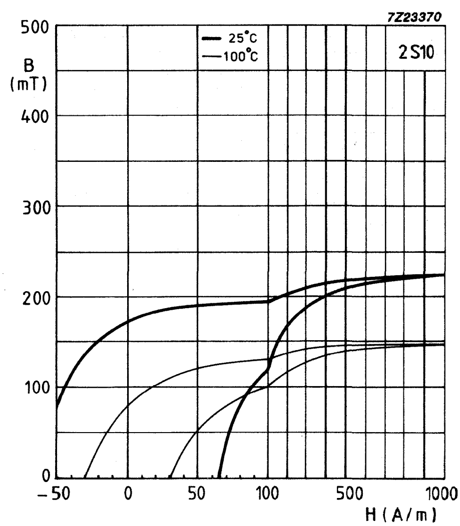


Fig.3 Typical B-H loops.

Material grade specification 3C11

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	≤ 10 kHz, 0.1 mT, 25 °C	4300 ± 20%	
B	10 kHz, 250 A/m, 25 °C	≥ 350	mT
	10 kHz, 250 A/m, 100 °C	≥ 180	mT
$\tan\delta/\mu_i$	100 kHz, 0.1 mT, 25 °C	$\leq 20.10^{-6}$	
	300 kHz, 0.1 mT, 25 °C	$\leq 200.10^{-6}$	
ρ	DC, 25 °C	≈ 1	Ωm
T_c		≥ 125	°C
density		≈ 4900	kg/m^3

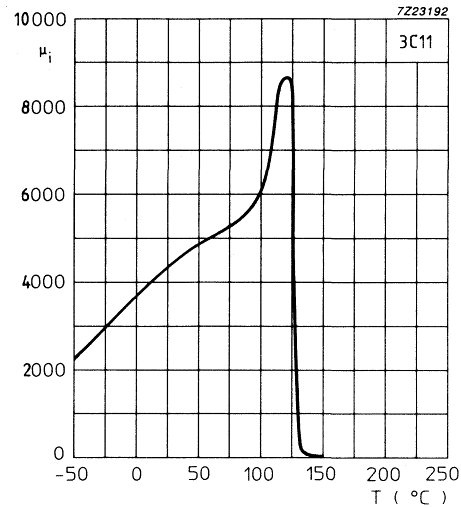


Fig.2 Initial permeability as a function of temperature.

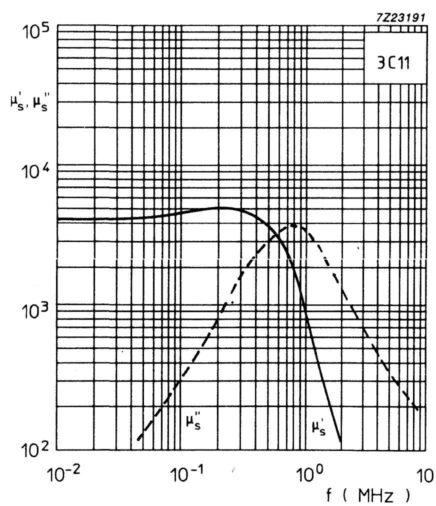


Fig.1 Complex permeability as a function of frequency.

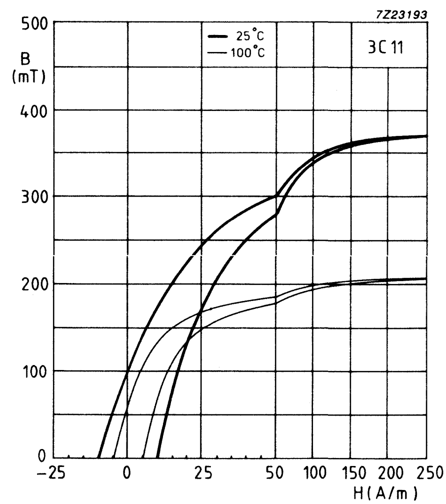


Fig.3 Typical B-H loops.

Material grade specification 3C11

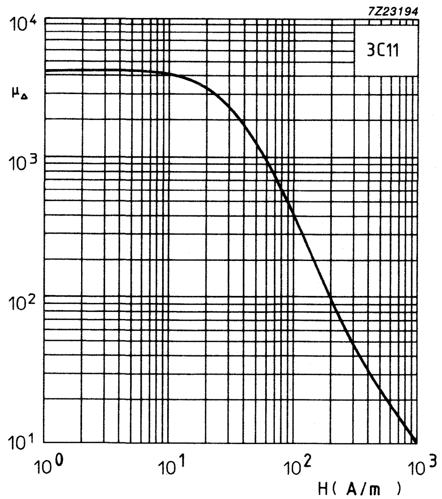


Fig.4 Incremental permeability as a function of magnetic field strength.

Material grade specification — 3C85

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	≤ 10 kHz, 0.1 mT, 25 °C	2000 ± 20%	
μ_a	25 kHz, 200 mT, 25 °C	4500 ± 25%	
	25 kHz, 200 mT, 100 °C	5500 ± 25%	
B	10 kHz, 250 A/m, 25 °C	≥ 400	mT
	10 kHz, 250 A/m, 100 °C	≥ 330	mT
P_V	25 kHz, 200 mT, 25 °C	≤ 190	kW/m³
	25 kHz, 200 mT, 100 °C	≤ 140	kW/m³
	100 kHz, 100 mT, 25 °C	≤ 230	kW/m³
	100 kHz, 100 mT, 100 °C	≤ 165	kW/m³
ρ	DC, 25 °C	≈ 2	Ωm
T_c		≥ 200	°C
density		≈ 4800	kg/m³

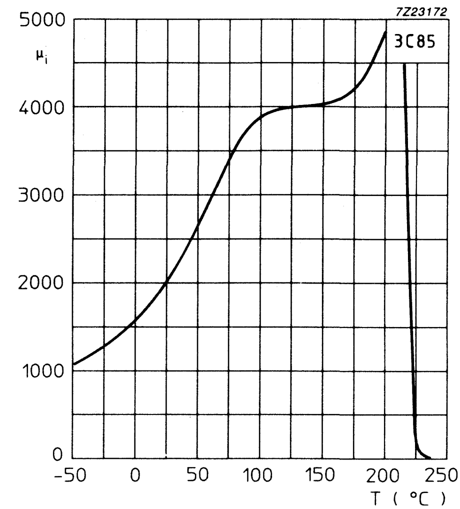


Fig.2 Initial permeability as a function of temperature.

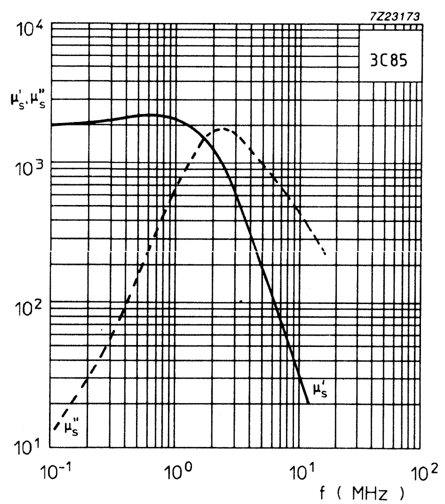


Fig.1 Complex permeability as a function of frequency.

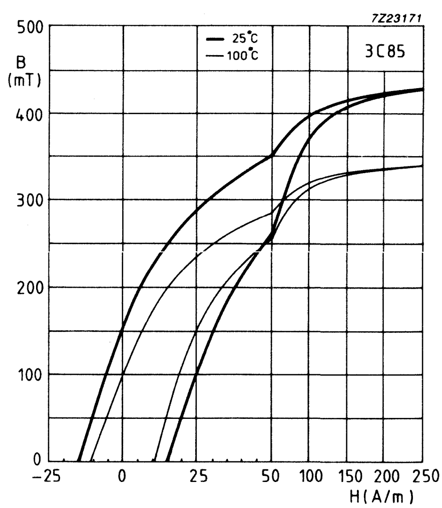


Fig.3 Typical B-H loops.

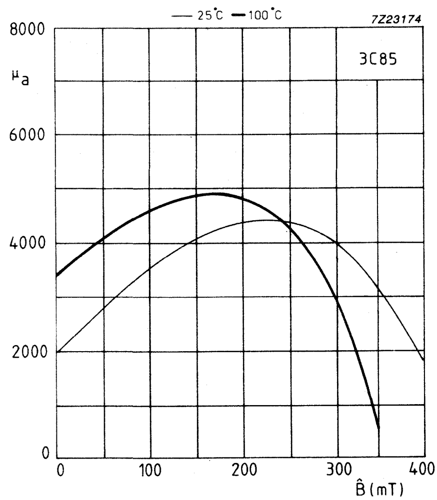


Fig.4 Amplitude permeability as a function of peak flux density.

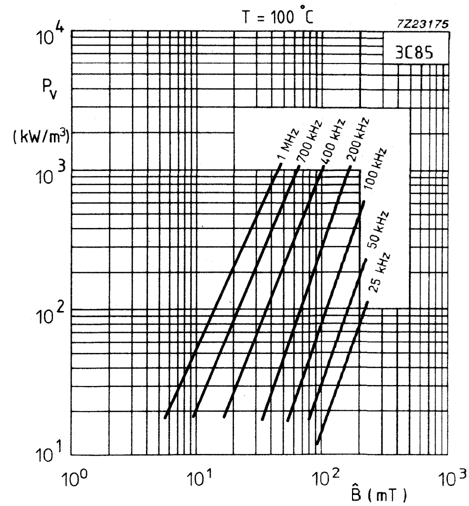


Fig.6 Specific power loss as a function of peak flux density with frequency as parameter.

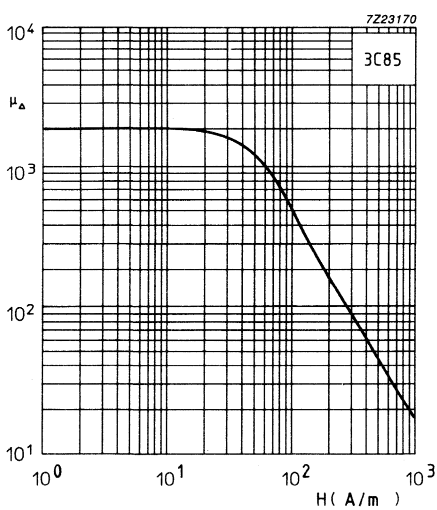


Fig.5 Incremental permeability as a function of magnetic field strength.

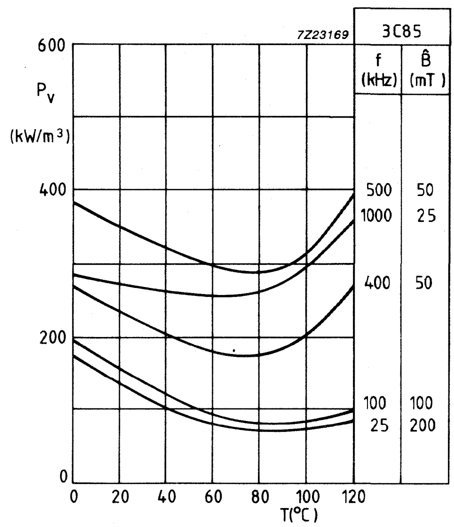


Fig.7 Specific power loss for several frequency/flux density combinations as a function of temperature.

Material grade specification 3E5

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	≤ 10 kHz, 0.1 mT, 25 °C	10000 ± 20%	
B	10 kHz, 250 A/m, 25 °C 10 kHz, 250 A/m, 100 °C	≈ 380 ≈ 210	mT mT
$\tan\delta/\mu_i$	30 kHz, 0.1 mT, 25 °C 100 kHz, 0.1 mT, 25 °C	$\leq 25.10^{-6}$ $\leq 75.10^{-6}$	
η_B	10 kHz, 1.5 - 3 mT, 25 °C	$\leq 1.10^{-3}$	T^{-1}
ρ	DC, 25 °C	≈ 0.5	Ωm
T_c		≥ 120	°C
density		≈ 4900	kg/m^3

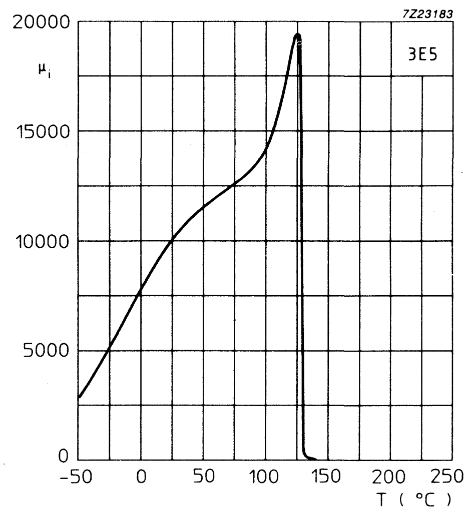


Fig.2 Initial permeability as a function of temperature.

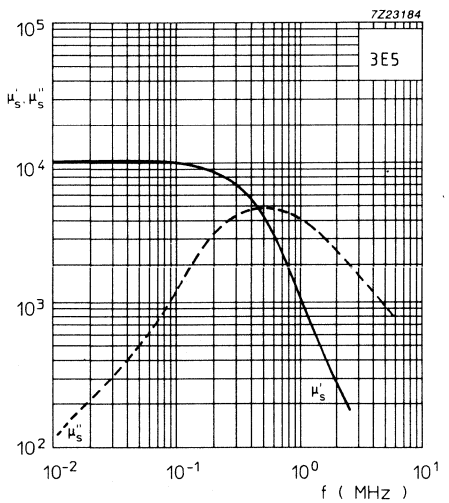


Fig.1 Complex permeability as a function of frequency.

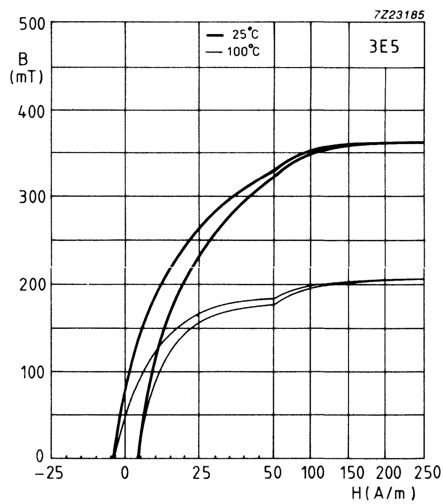


Fig.3 Typical B-H loops.

Material grade specification 3E5

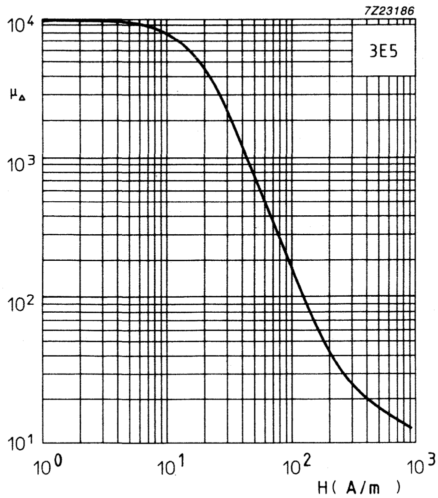


Fig.4 Incremental permeability as a function of magnetic field strength.

Material grade specification 3E25

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	≤ 10 kHz, 0.1 mT, 25 °C 100 kHz, 0.1 mT, 25 °C	6000 ± 20% 6000 + 30%/ - 20%	
B	10 kHz, 250 A/m, 25 °C 10 kHz, 250 A/m, 100 °C	≥ 350 ≥ 180	mT mT
$\tan\delta/\mu_i$	100 kHz, 0.1 mT, 25 °C 300 kHz, 0.1 mT, 25 °C	$\leq 25.10^{-6}$ $\leq 200.10^{-6}$	
ρ	DC, 25 °C	≈ 0.5	Ωm
T_C		≥ 125	°C
density		≈ 4900	kg/m^3

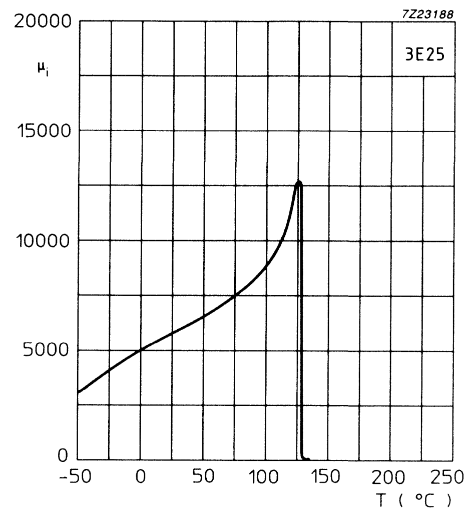


Fig.2 Initial permeability as a function of temperature.

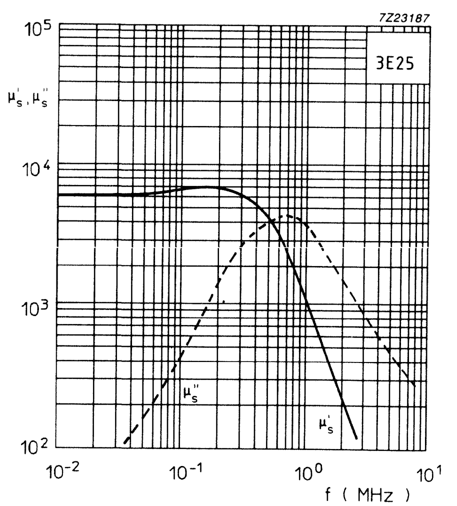


Fig.1 Complex permeability as a function of frequency.

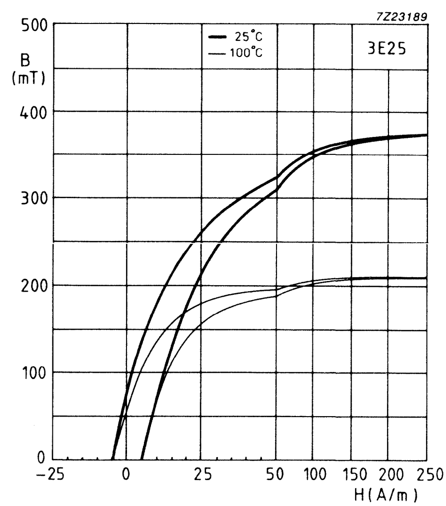


Fig.3 Typical B-H loops.

Material grade specification 3E25

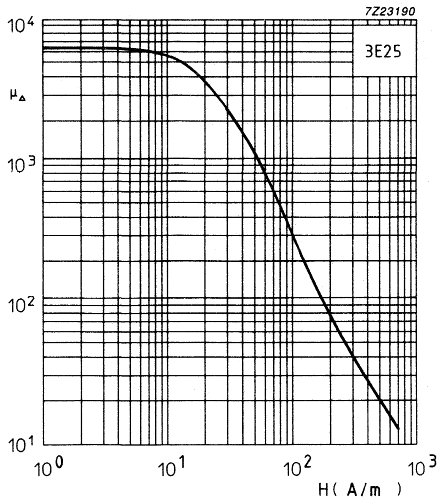


Fig.4 Incremental permeability as a function of magnetic field strength.

Material grade specification 3F3

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	≤ 10 kHz, 0.1 mT, 25 °C	1800 ± 20%	
μ_a	25 kHz, 200 mT, 25 °C	≈ 4000	
	25 kHz, 200 mT, 100 °C	≈ 4000	
B	10 kHz, 250 A/m, 25 °C	≥ 400	mT
	10 kHz, 250 A/m, 100 °C	≥ 330	mT
P_V	100 kHz, 100 mT, 100 °C	≤ 80	kW/m³
	400 kHz, 50 mT, 100 °C	≤ 150	kW/m³
ρ	DC, 25 °C	≈ 2	Ωm
T_c		≥ 200	°C
density		≈ 4750	kg/m³

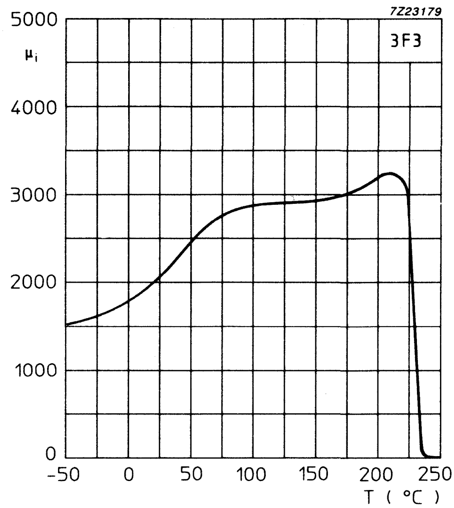


Fig.2 Initial permeability as a function of temperature.

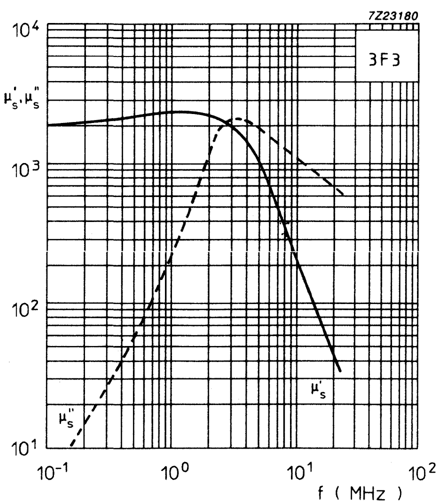


Fig.1 Complex permeability as a function of frequency.

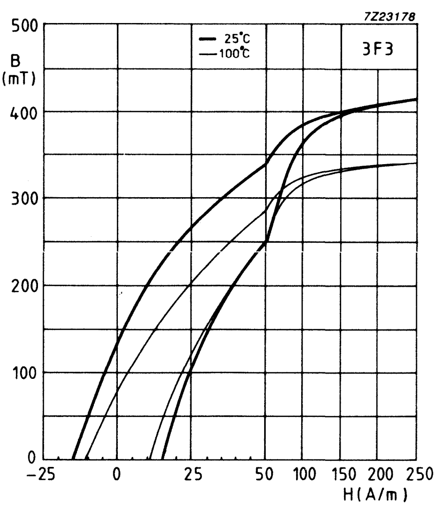


Fig.3 Typical B-H loops.

Material grade specification 3F3

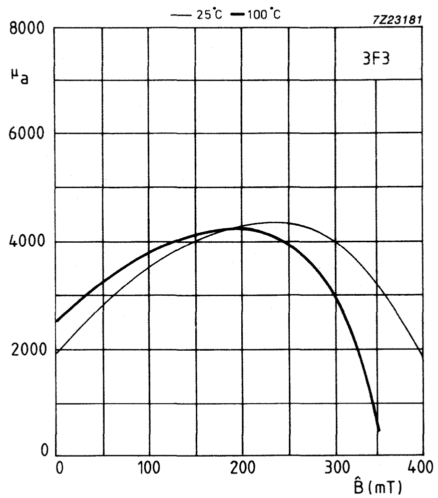


Fig.4 Amplitude permeability as a function of peak flux density.

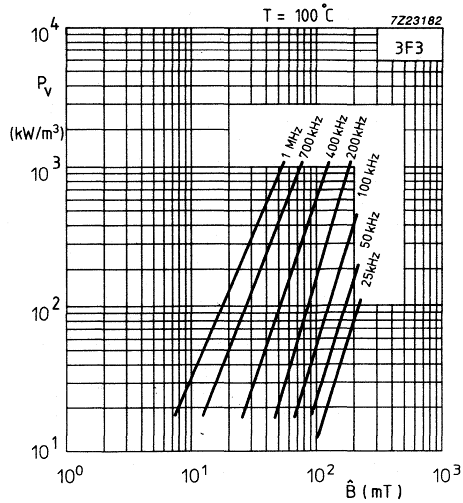


Fig.6 Specific power loss as a function of peak flux density with frequency as parameter.

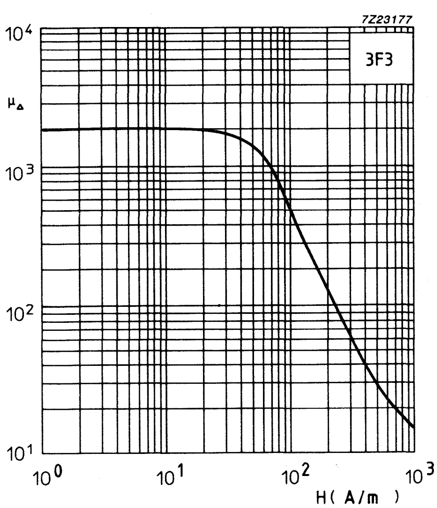


Fig.5 Incremental permeability as a function of magnetic field strength.

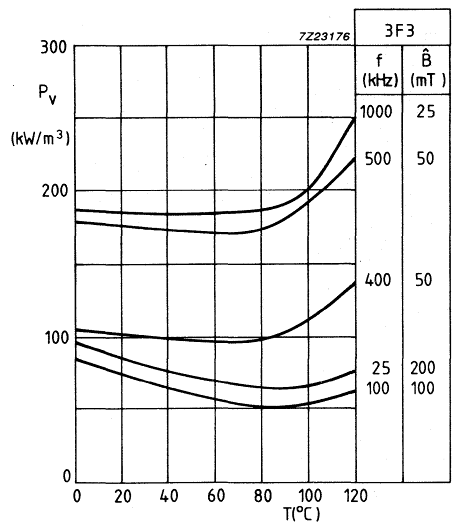


Fig.7 Specific power loss for several frequency/flux density combinations as a function of temperature.

Material grade specification 3F4

	CONDITIONS	VALUE	UNIT
μ_i	≤10 kHz, 0.1 mT, 25 °C	750 ±20%	
μ_a	25 kHz, 200 mT, 25 °C	≈1300	
	25 kHz, 200 mT, 100 °C	≈1400	
B	10 kHz, 250 A/m, 25 °C	≥350	mT
	10 kHz, 250 A/m, 100 °C	≥300	mT
P_V	1 MHz, 30 mT, 100 °C	≤300	kW/m³
	3 MHz, 10 mT, 100 °C	≤300	kW/m³
ρ	DC, 25 °C	≈10	Ωm
T_c		≥220	°C
density		≈4700	kg/m³

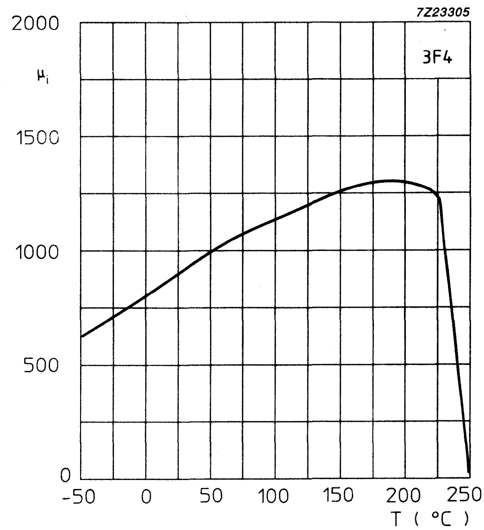


Fig.2 Initial permeability as a function of temperature.

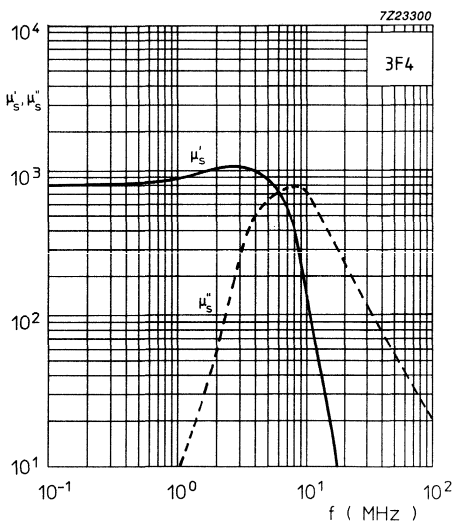


Fig.1 Complex permeability as a function of frequency.

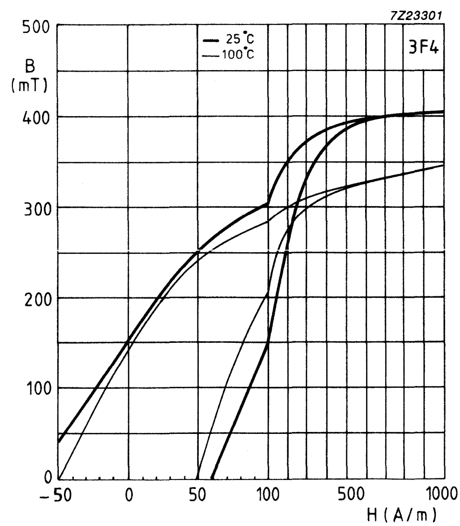


Fig.3 Typical B-H loops.

Material grade specification 3F4

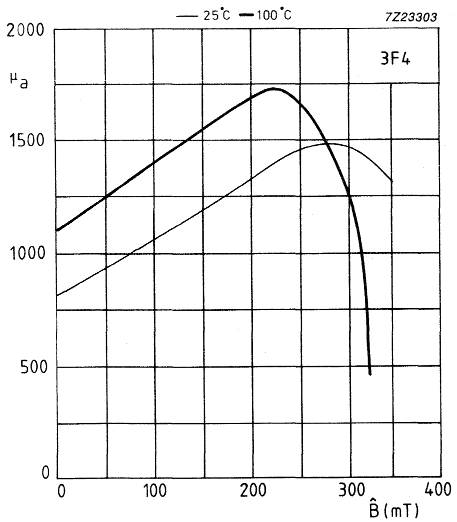


Fig.4 Amplitude permeability as a function of peak flux density.

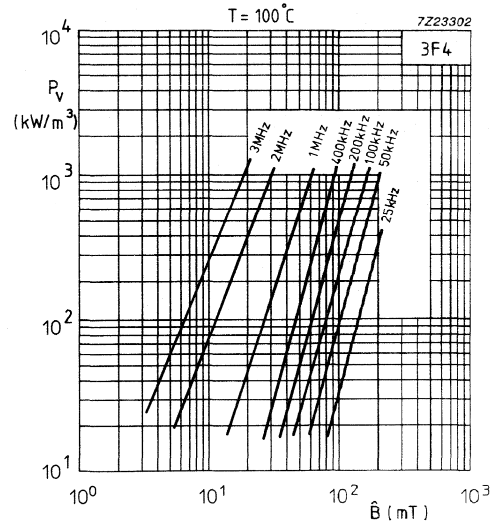


Fig.6 Specific power loss as a function of peak flux density with frequency as parameter.

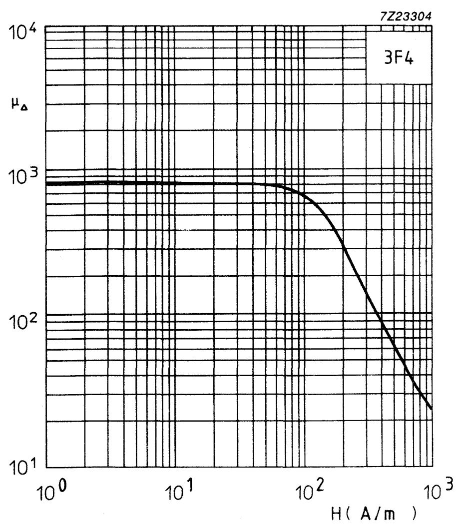


Fig.5 Incremental permeability as a function of magnetic field strength.

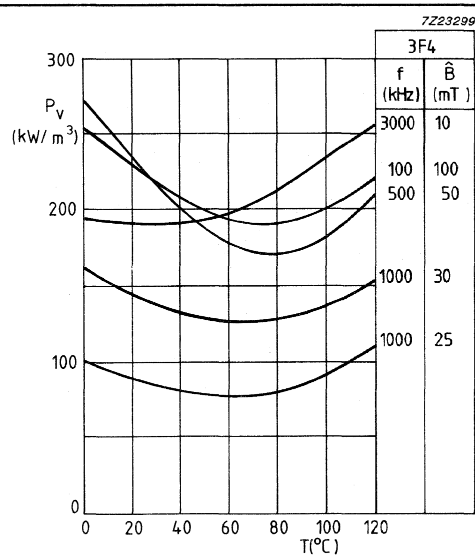


Fig.7 Specific power loss for several frequency/flux density combinations as a function of temperature.

Material grade specification 3R1

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	≤ 10 kHz, 0.1 mT, 25 °C	800 ± 20%	
B	10 kHz, 250 A/m, 25 °C 10 kHz, 250 A/m, 100 °C	≈ 390 ≈ 300	mT mT
B_r	from 1 kA/m, 25 °C from 1 kA/m, 100 °C	340 ± 25 250 ± 25	mT mT
H_c	after 1 kA/m, 25 °C after 1 kA/m, 100 °C	42 ± 10 20 ± 5	A/m A/m
ρ	DC, 25 °C	≈ 1	Ωm
T_c		≥ 200	°C
density		≈ 4700	kg/m^3

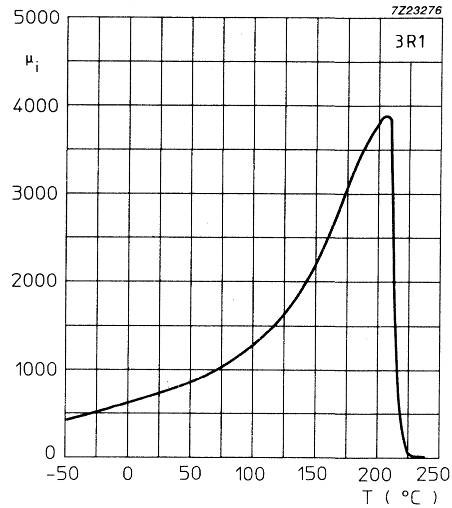


Fig.2 Initial permeability as a function of temperature.

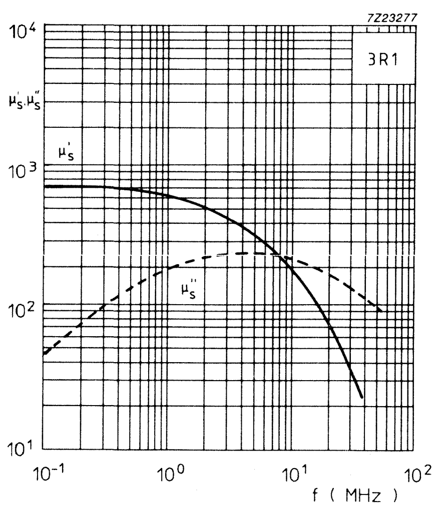


Fig.1 Complex permeability as a function of frequency.

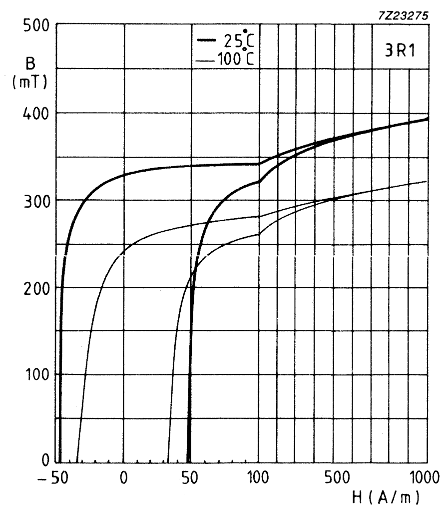


Fig.3 Typical B-H loops.

Material grade specification 4A11

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	≤ 10 kHz, 0.1 mT, 25 °C	700 ± 20%	
B	10 kHz, 250 A/m, 25 °C 10 kHz, 250 A/m, 100 °C	≈ 270 ≈ 180	mT mT
$\tan\delta/\mu_i$	1 MHz, 0.1 mT, 25 °C 3 MHz, 0.1 mT, 25 °C	$\leq 100.10^{-6}$ $\leq 1000.10^{-6}$	
ρ	DC, 25 °C	$\approx 10^5$	Ωm
T_c		≥ 125	°C
density		≈ 5100	kg/m^3

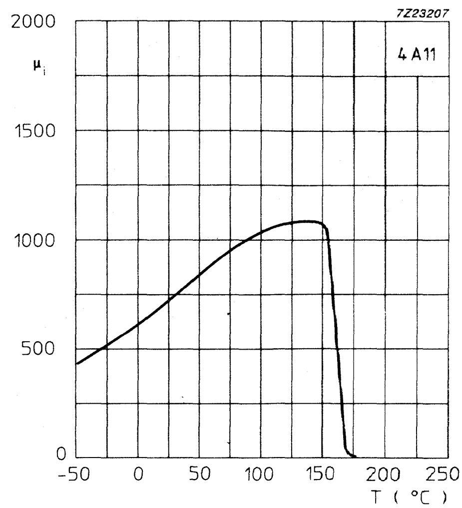


Fig.2 Initial permeability as a function of temperature.

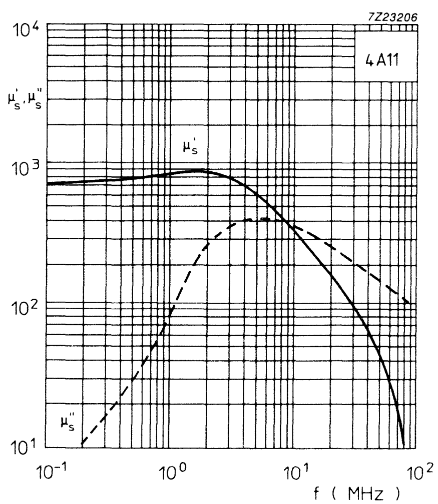


Fig.1 Complex permeability as a function of frequency.

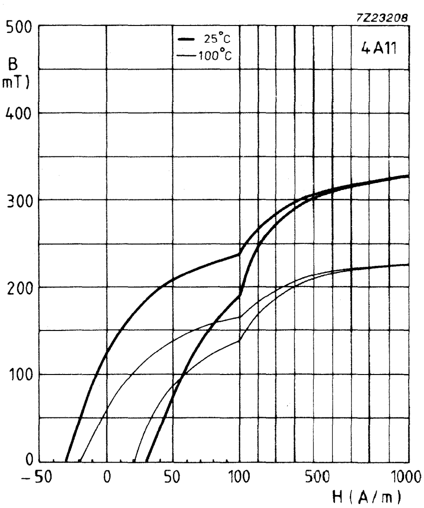


Fig.3 Typical B-H loops.

Material grade specification 4A15

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	≤10 kHz, 0.1 mT, 25 °C	1200 ±20%	
B	10 kHz, 250 A/m, 25 °C	≈300	mT
	10 kHz, 250 A/m, 100 °C	≈180	mT
$\tan\delta/\mu_i$	1 MHz, 0.1 mT, 25 °C	$\leq 250.10^{-6}$	
	3 MHz, 0.1 mT, 25 °C	$\leq 1500.10^{-6}$	
ρ	DC, 25 °C	$\approx 10^5$	Ωm
T_c		≥125	°C
density		≈5100	kg/m^3

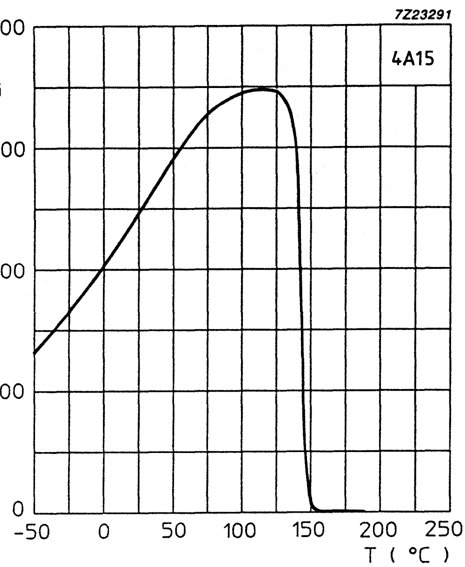


Fig.2 Initial permeability as a function of temperature.

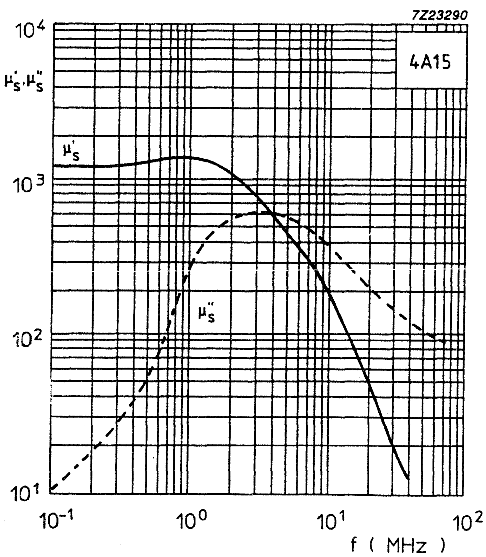


Fig.1 Complex permeability as a function of frequency.

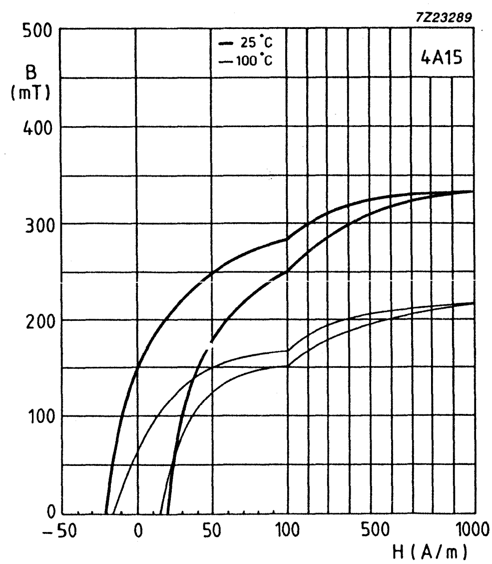


Fig.3 Typical B-H loops.

Material grade specification 4B1

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	≤ 10 kHz, 0.1 mT, 25 °C	250 ± 20%	
B	10 kHz, 250 A/m, 25 °C 10 kHz, 250 A/m, 100 °C	≈ 310 ≈ 260	mT mT
$\tan\delta/\mu_i$	1 MHz, 0.1 mT, 25 °C 3 MHz, 0.1 mT, 25 °C	$\leq 90.10^{-6}$ $\leq 300.10^{-6}$	
ρ	DC, 25 °C	$\approx 10^5$	Ωm
T_C		≥ 250	°C
density		≈ 4600	kg/m^3

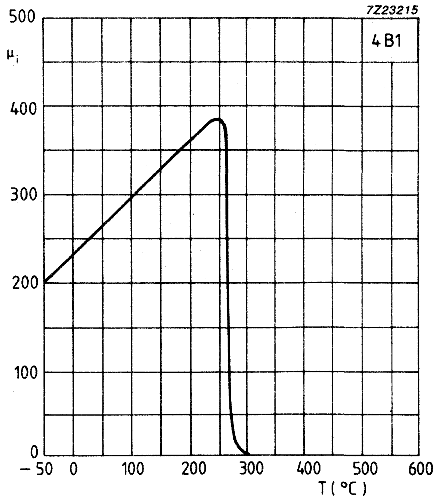


Fig.2 Initial permeability as a function of temperature.

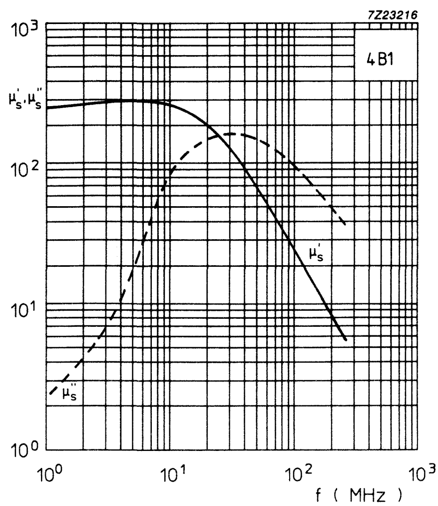


Fig.1 Complex permeability as a function of frequency.

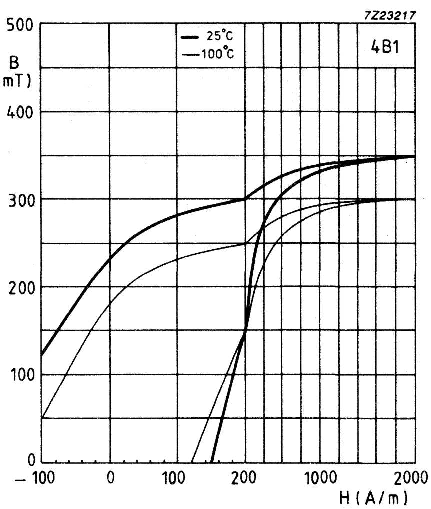


Fig.3 Typical B-H loops.

Material grade specification 4B3

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	≤10 kHz, 0.1 mT, 25 °C	300 ±20%	
B	10 kHz, 250 A/m, 25 °C	≈300	mT
	10 kHz, 250 A/m, 100 °C	≈250	mT
ρ	DC, 25 °C	≈10^5	Ωm
T_c		≥250	°C
density		≈5000	kg/m³

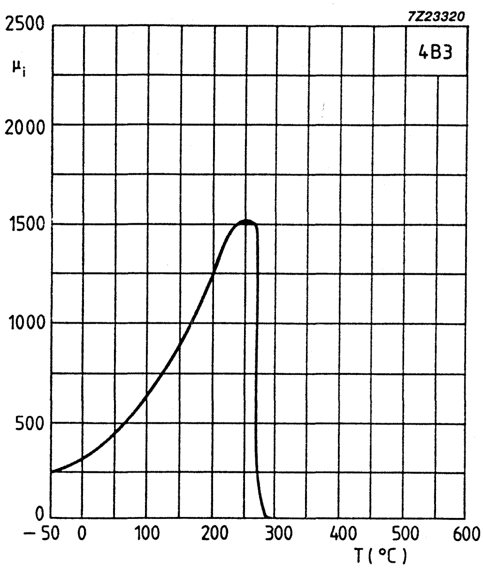


Fig.2 Initial permeability as a function of temperature.

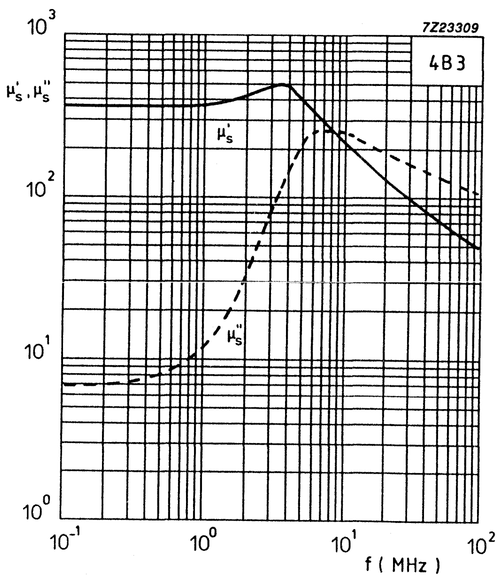


Fig.1 Complex permeability as a function of frequency.

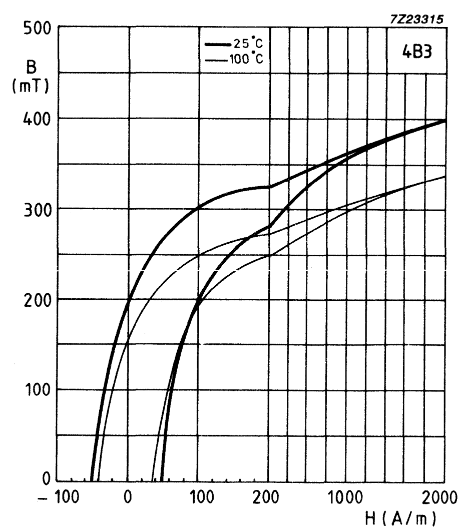


Fig.3 Typical B-H loops.

Material grade specification 4C65

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	≤ 10 kHz, 0.1 mT, 25 °C	125 ± 20%	
B	10 kHz, 250 A/m, 25 °C 10 kHz, 250 A/m, 100 °C	≈ 300 ≈ 250	mT mT
$\tan\delta/\mu_i$	3 MHz, 0.1 mT, 25 °C 10 MHz, 0.1 mT, 25 °C	$\leq 80.10^{-6}$ $\leq 130.10^{-6}$	
ρ	DC, 25 °C	$\approx 10^5$	Ωm
T_C		≥ 350	°C
density		≈ 4500	kg/m^3

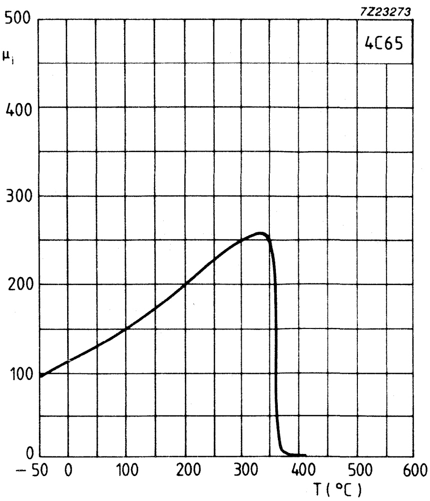


Fig.2 Initial permeability as a function of temperature.

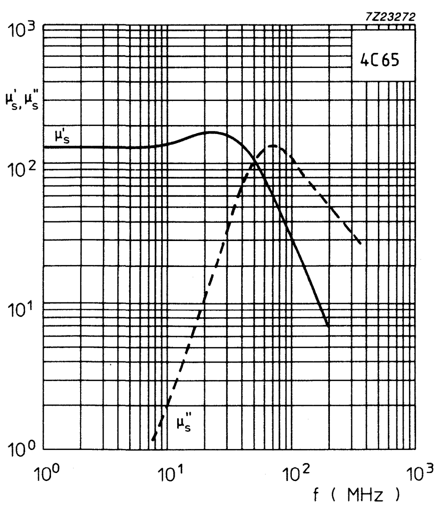


Fig.1 Complex permeability as a function of frequency.

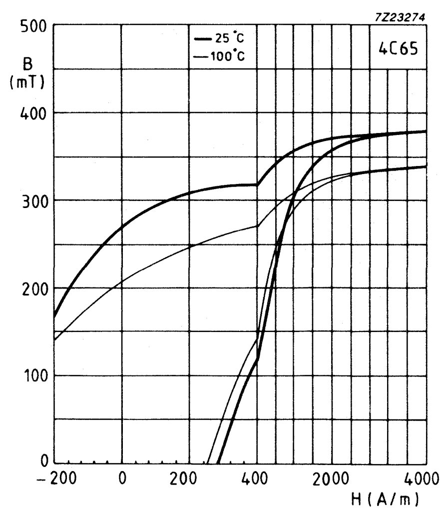


Fig.3 Typical B-H loops.

Material grade specification 4D2

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	≤ 10 kHz, 0.1 mT, 25 °C	60 ± 20%	
B	10 kHz, 250 A/m, 25 °C 10 kHz, 250 A/m, 100 °C	≈ 200 ≈ 180	mT mT
$\tan\delta/\mu_i$	10 MHz, 0.1 mT, 25 °C 30 MHz, 0.1 mT, 25 °C	$\leq 100.10^{-6}$ $\leq 600.10^{-6}$	
ρ	DC, 25 °C	$\approx 10^5$	Ωm
T_C		≥ 400	°C
density		≈ 4200	kg/m^3

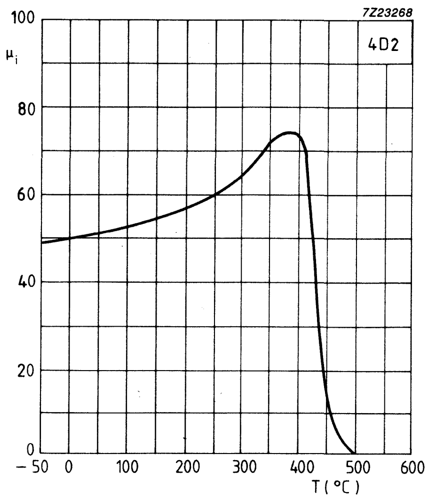


Fig.2 Initial permeability as a function of temperature.

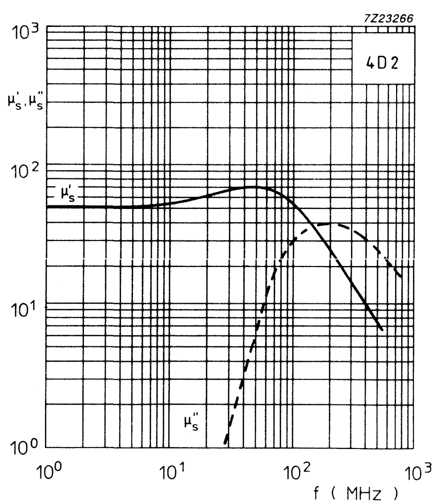


Fig.1 Complex permeability as a function of frequency.

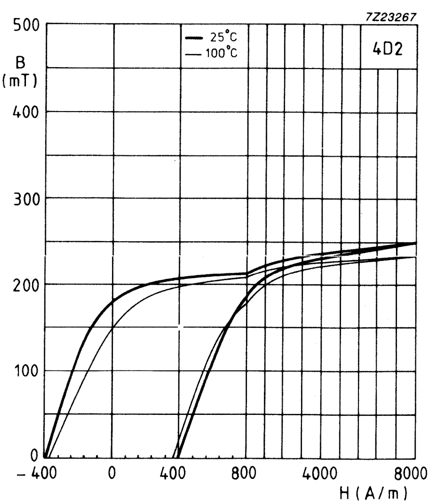


Fig.3 Typical B-H loops.

Material grade specification 4E1

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	≤ 10 kHz, 0.1 mT, 25 °C	15 ± 20%	
B	10 kHz, 250 A/m, 25 °C 10 kHz, 250 A/m, 100 °C	≈ 80 ≈ 75	mT mT
$\tan\delta/\mu_i$	10 MHz, 0.1 mT, 25 °C 30 MHz, 0.1 mT, 25 °C	$\leq 300.10^{-6}$ $\leq 350.10^{-6}$	
ρ	DC, 25 °C	$\approx 10^5$	Ωm
T_C		≥ 500	°C
density		≈ 3700	kg/m³

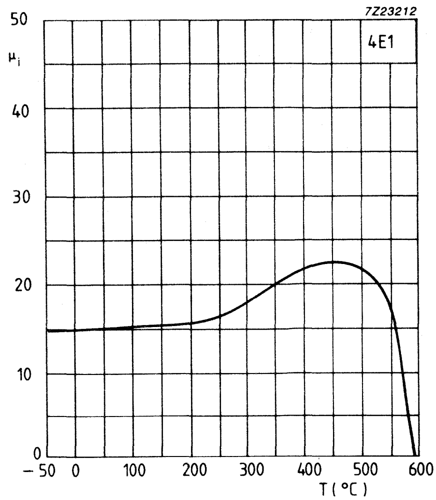


Fig.2 Initial permeability as a function of temperature.

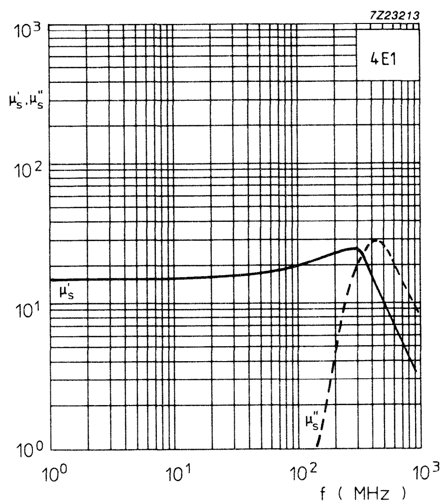


Fig.1 Complex permeability as a function of frequency.

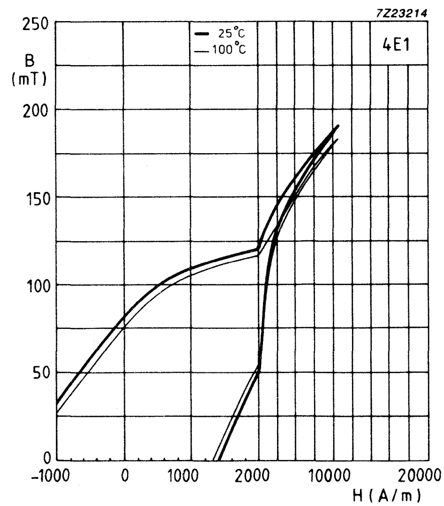


Fig.3 Typical B-H loops.

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Material grade specification 4E2

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	≤10 kHz, 0.1 mT, 25 °C	25 ±20%	
B	10 kHz, 250 A/m, 25 °C	≈150	mT
	10 kHz, 250 A/m, 100 °C	≈150	mT
ρ	DC, 25 °C	≈10^5	Ωm
T_c		≥400	°C
density		≈4000	kg/m³

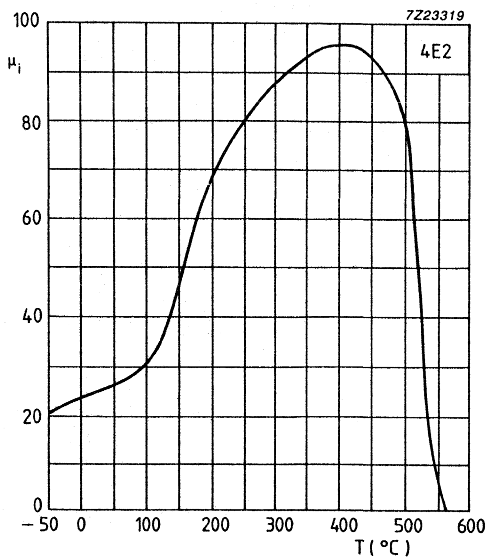


Fig.2 Initial permeability as a function of temperature.

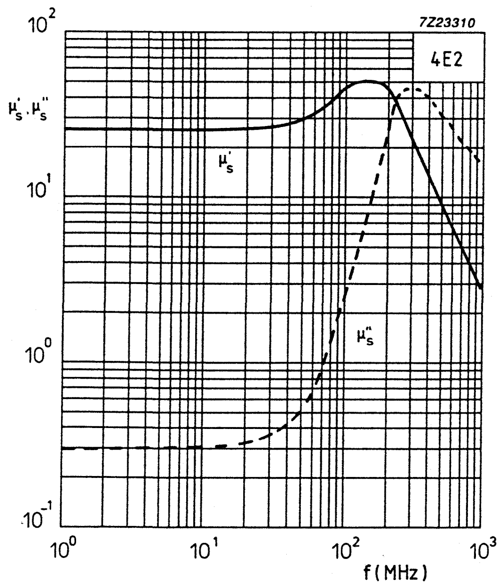


Fig.1 Complex permeability as a function of frequency.

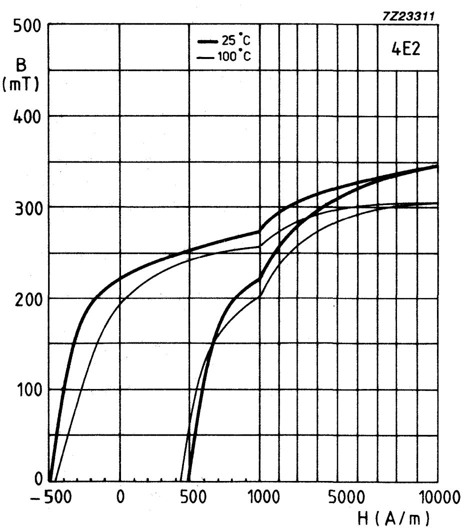


Fig.3 Typical B-H loops.

Preliminary
Material grade specification

4F1

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	<10 kHz, 0.1 mT, 25 °C	≈80	
μ_a	25 kHz, 200 mT, 25 °C	≈400	
	25 kHz, 200 mT, 100 °C	≈300	
B	10 kHz, 250 A/m, 25 °C	≥50	mT
	10 kHz, 250 A/m, 100 °C	≥100	mT
P_V	3 MHz, 10 mT, 100 °C	≤200	kW/m³
	10 MHz, 5 mT, 100 °C	≤200	kW/m³
ρ	DC, 25 °C	≈10⁵	Ωm
T_c		≥260	°C
density		≈4600	kg/m³

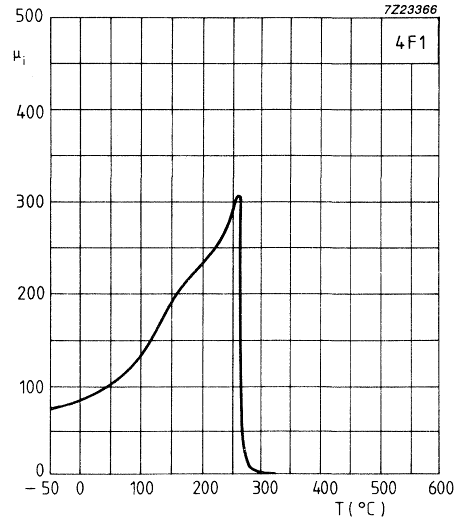


Fig.2 Initial permeability as a function of temperature.

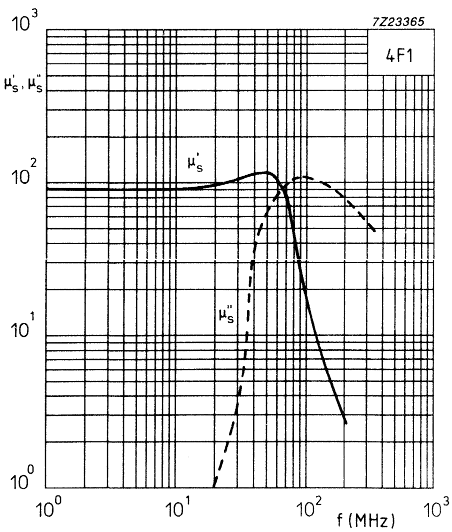


Fig.1 Complex permeability as a function of frequency.

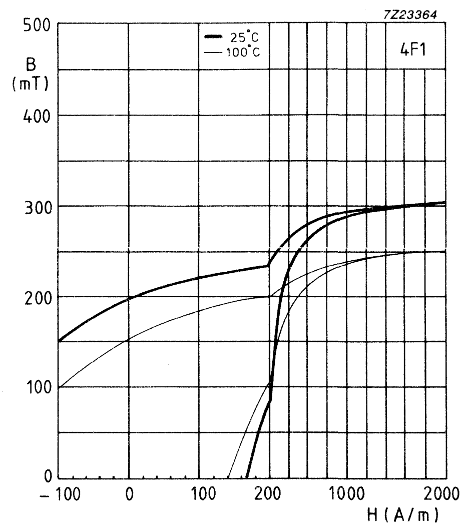


Fig.3 Typical B-H loops.

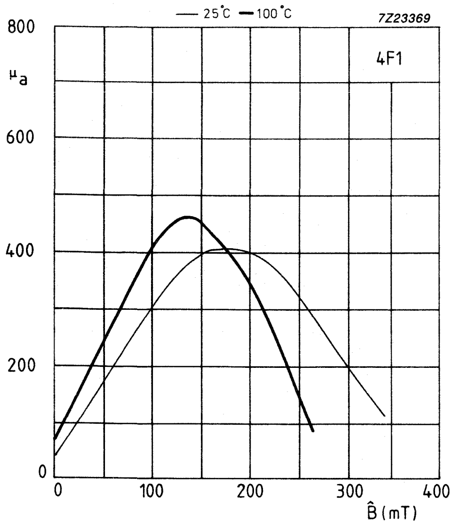


Fig.4 Amplitude permeability as a function of peak flux density.

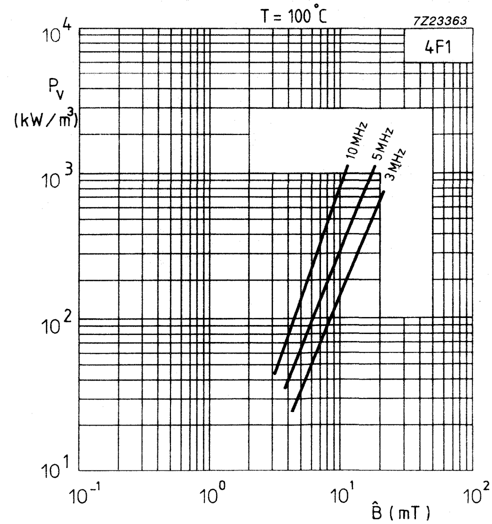


Fig.6 Specific power loss as a function of peak flux density with frequency as parameter.

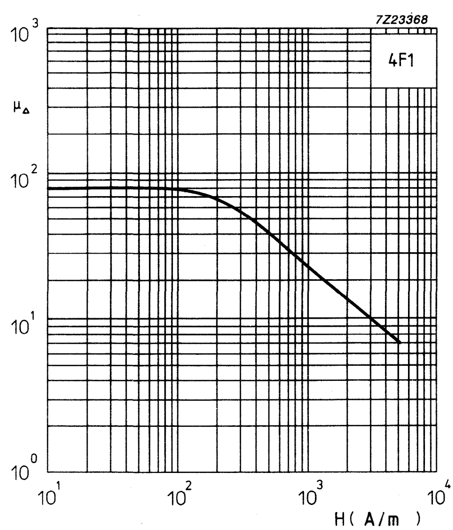


Fig.5 Incremental permeability as a function of magnetic field strength.

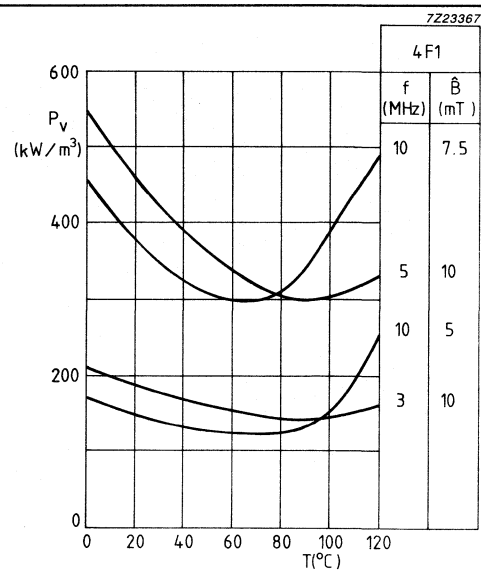


Fig.7 Specific power loss for several frequency/flux density combinations as a function of temperature.

Material grade specification 4M2

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	≤10 kHz, 0.1 mT, 25 °C	300 ±20%	
B	10 kHz, 250 A/m, 25 °C 10 kHz, 250 A/m, 100 °C	≈300 ≈260	mT mT
ρ	DC, 25 °C	≈10^5	Ωm
T_c		≥250	°C
density		≈5000	kg/m³

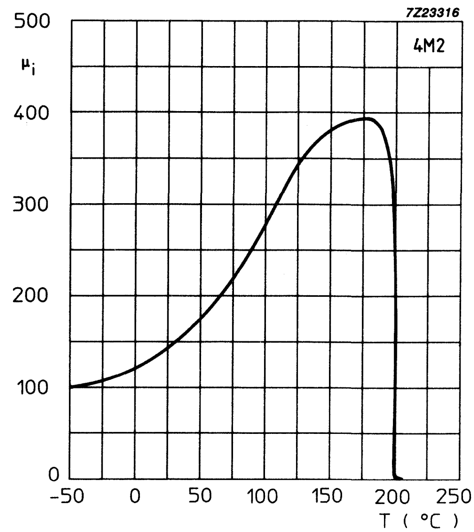


Fig.2 Initial permeability as a function of temperature.

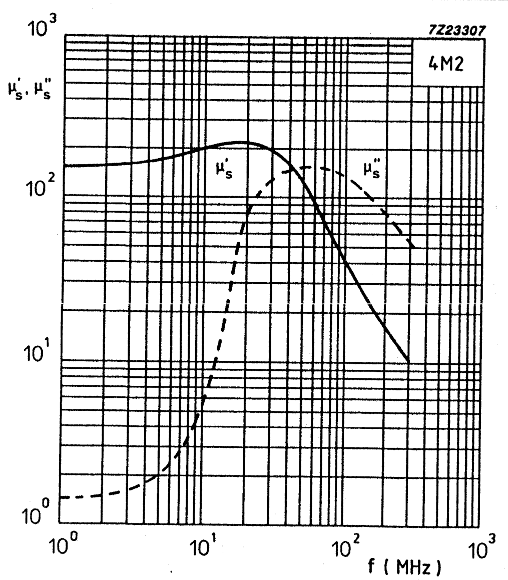


Fig.1 Complex permeability as a function of frequency.

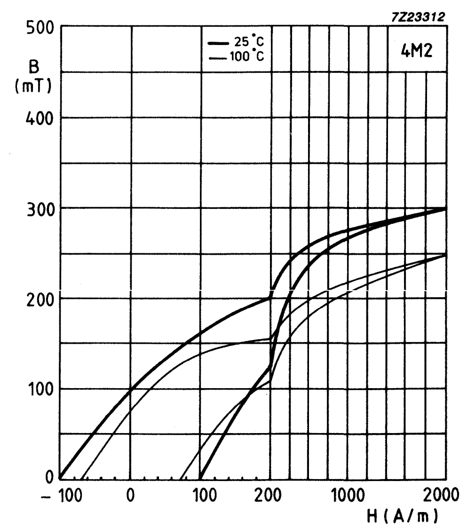


Fig.3 Typical B-H loops.

Material grade specification 4S10

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	≤10 kHz, 0.1 mT, 25 °C	1200 ±20%	
B	10 kHz, 250 A/m, 25 °C	≈300	mT
ρ	DC, 25 °C	≈10^5	Ωm
T_c		≥125	°C
density		≈5100	kg/m³

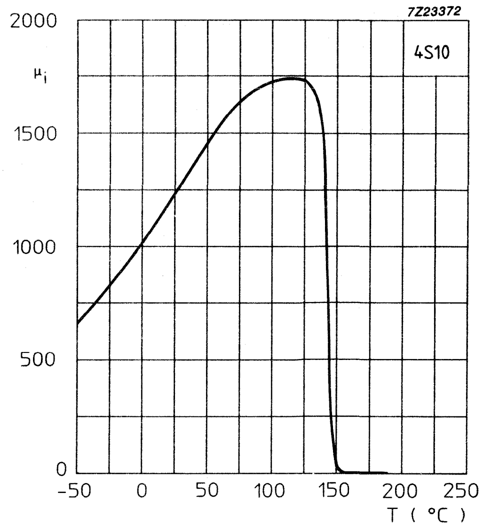


Fig.2 Initial permeability as a function of temperature.

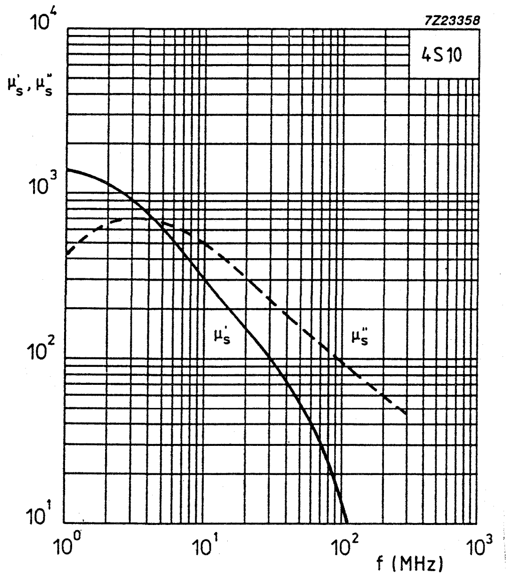


Fig.1 Complex permeability as a function of frequency.

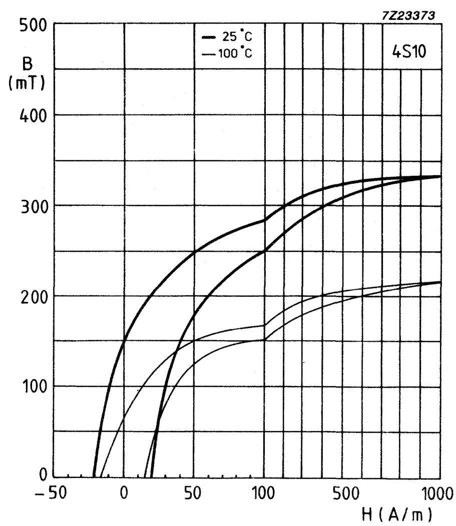


Fig.3 Typical B-H loops.

Material grade specification 8C11

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	≤10 kHz, 0.1 mT, 25 °C	1200 ±20%	
B	10 kHz, 250 A/m, 25 °C 10 kHz, 250 A/m 100 °C	≈300 ≈200	mT mT
ρ	DC, 25 °C	≈10^5	Ωm
T_c		≥125	°C
density		≈5100	kg/m³

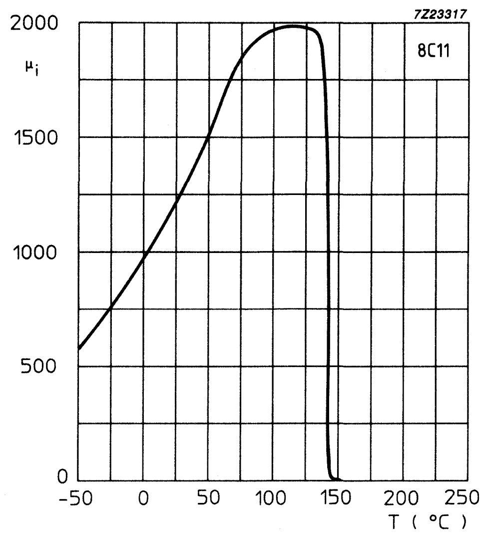


Fig.2 Initial permeability as a function of temperature.

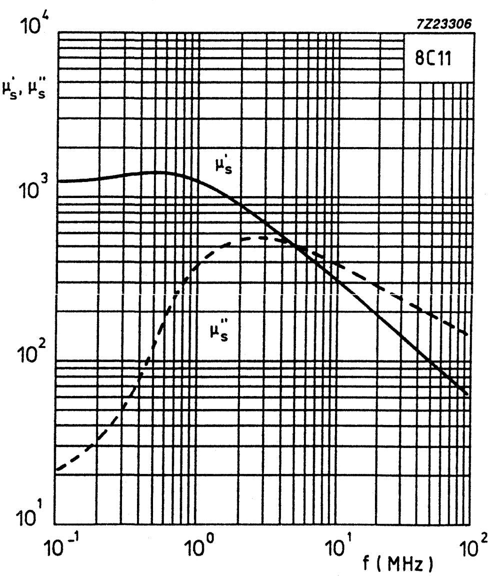


Fig.1 Complex permeability as a function of frequency.

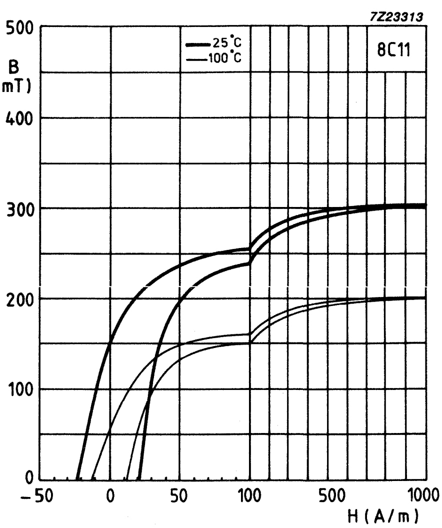


Fig.3 Typical B-H loops.

Material grade specification 8C12

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	≤10 kHz, 0.1 mT, 25 °C	900 ±20%	
B	10 kHz, 250 A/m, 25 °C	≈230	mT
	10 kHz, 250 A/m 100 °C	≈150	mT
ρ	DC, 25 °C	$\approx 10^5$	Ωm
T_c		≥125	°C
density		≈5000	kg/m^3

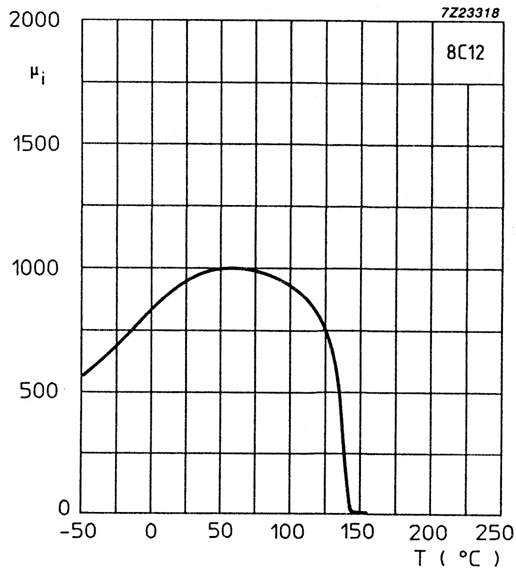


Fig.2 Initial permeability as a function of temperature.

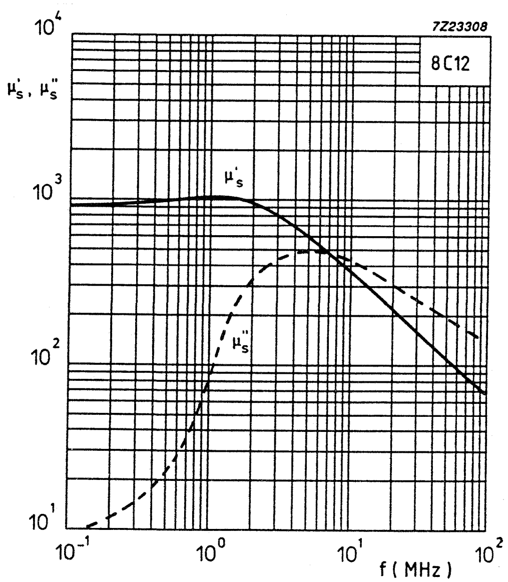


Fig.1 Complex permeability as a function of frequency.

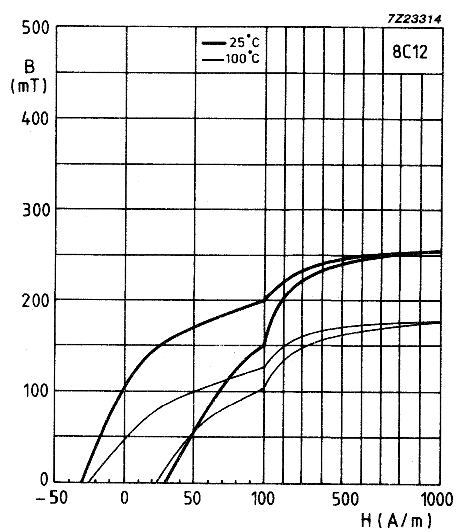


Fig.3 Typical B-H loops.

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 grades

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 material grades 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. Other sizes than those mentioned in the tables below 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 ferrite grades in accelerator applications

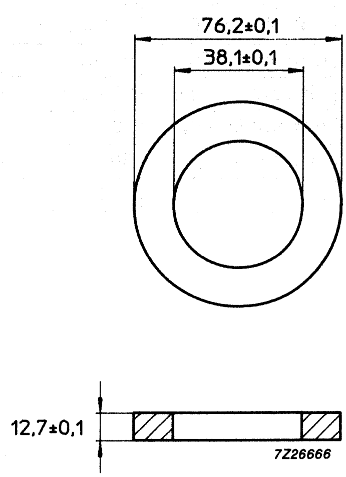
Properties specified in this section are related to room temperature (25 °C) unless otherwise stated. They have been measured on sintered, non ground ring cores of dimension ∅25 x ∅15 x 10 mm which are not subjected to external stresses.

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.

MATERIAL	8C11	8C12	4M2	4E2	4B3
μ_i (±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 (Ω M)	>10^3	>10^3	>10^3	>10^3	>10^3
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			
100 mT					
500 kHz					
10 mT		10.10^3			
20 mT		6.10^3			
50 mT		$2.5.10^3$			
100 mT					
1 MHz					
5 mT		10.10^3	20.10^3		
10 mT		$7.5.10^3$	20.10^3		
20 mT		5.10^3	15.10^3		
30 mT			8.10^3		
50 mT					
2.5 MHz					
5 mT			20.10^3		
10 mT			20.10^3		
20 mT			15.10^3		
30 mT			7.10^3		
5 MHz					
5 mT			15.10^3		
10 mT			15.10^3		
20 mT			10.10^3		
30 mT			7.10^3		
10 MHz					
5 mT			12.10^3		
10 mT			10.10^3		
80 MHz					
1 mT				$2.5.10^3$	
100 MHz				2.10^3	

MATERIAL	8C11	8C12	4M2	4E2	4B3
Decrease in μQ (in %), measured 10 ms after application of DC bias (approx.)		10	15	30	
μ_{Δ} 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 - 10	2 - 10	20 - 100	
Application area and special features	kickers; 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 | RC76/38/13



Dimensions in mm.

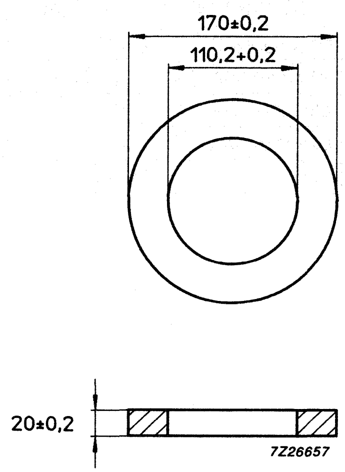
Fig.1 Ring core RC76/38/13.

Effective core parameters

SYMBOL	PARAMETER	VALUE	UNIT
Σ(l/A)	core factor (C1)	0.716	mm^{-1}
V_e	effective volume	38 500	mm^3
l_e	effective length	166	mm
A_e	effective area	232	mm^2
	mass	≈220	g

GRADE	A_L (nH)	ORDERING CODE
4M2	≈250	4322 020 9251
8C11	≈2000	4322 020 9252
8C12	≈1600	4322 020 9253

Ferrite for particle accelerators RC170/110/20



Dimensions in mm.

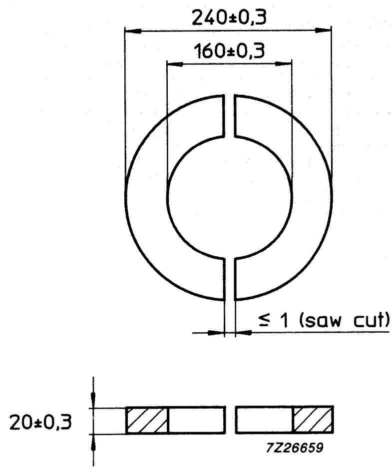
Fig.1 Ring core RC170/110/20.

GRADE	A_L (nH)	ORDERING CODE
8C11	≈2600	4322 020 9342

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

Ferrite for particle accelerators RC240/160/20



Dimensions in mm.

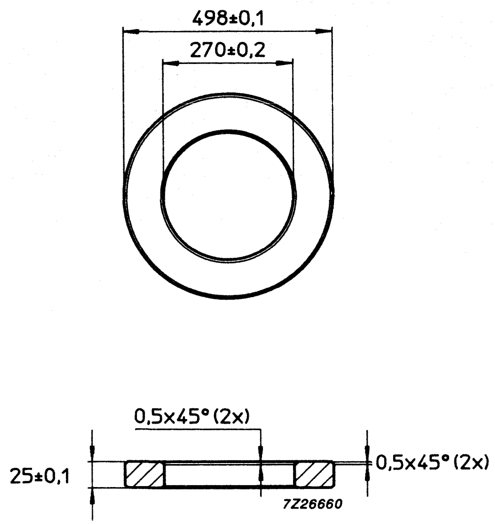
Fig.1 Split ring core RC240/160/20.

Effective core parameters

SYMBOL	PARAMETER	VALUE	UNIT
Σ(l/A)	core factor (C1)	0.774	mm^{-1}
V_e	effective volume	482 000	mm^3
l_e	effective length	611	mm
A_e	effective area	789	mm^2
	mass	≈2500	g

GRADE	A_L (nH)	ORDERING CODE
8C11	–	4322 020 9322

Ferrite for particle accelerators RC498/270/25



Dimensions in mm.

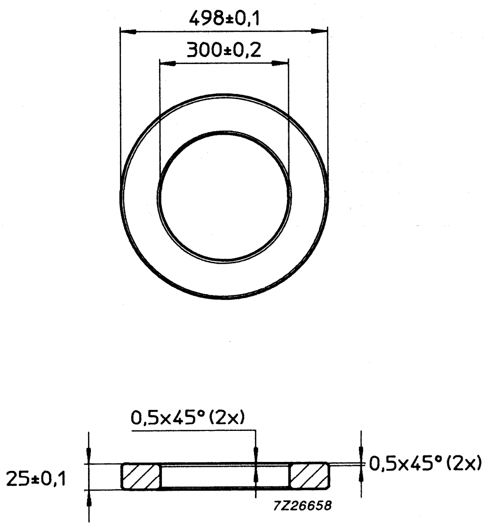
Fig.1 Ring core RC498/270/25.

Effective core parameters

SYMBOL	PARAMETER	VALUE	UNIT
$\Sigma(l/A)$	core factor (C1)	0.409	mm^{-1}
V_e	effective volume	3 120 000	mm^3
l_e	effective length	1130	mm
A_e	effective area	2760	mm^2
	mass	≈17 000	g

GRADE	A_L (nH)	ORDERING CODE
8C12	≈2800	4322 020 9309

Ferrite for particle accelerators — RC498/300/25



Dimensions in mm.

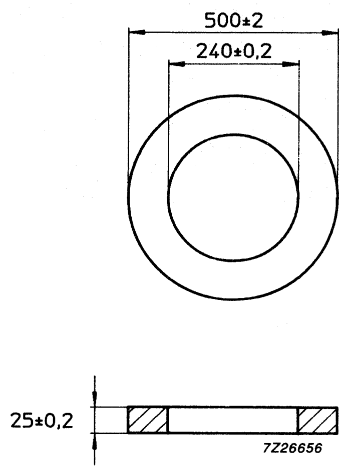
Fig.1 Ring core RC498/300/25.

GRADE	A_L (nH)	ORDERING CODE
8C12	≈2300	4322 020 9309

Effective core parameters

SYMBOL	PARAMETER	VALUE	UNIT
$\Sigma(l/A)$	core factor (C1)	0.496	mm^{-1}
V_e	effective volume	2 900 000	mm^3
l_e	effective length	1200	mm
A_e	effective area	2420	mm^2
	mass	≈15 000	g

Ferrite for particle accelerators RC500/240/25



Dimensions in mm.

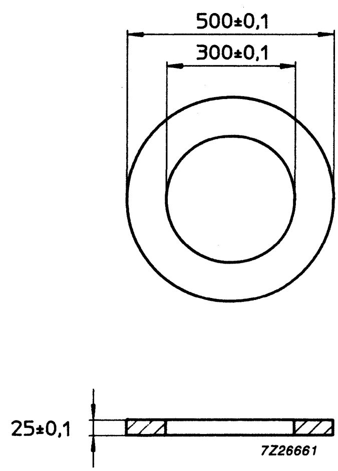
Fig.1 Ring core RC500/240/25.

GRADE	A_L (nH)	ORDERING CODE
4B3	≈1300	4322 020 9346

Effective core parameters

SYMBOL	PARAMETER	VALUE	UNIT
$\Sigma(l/A)$	core factor (C1)	0.342	mm^{-1}
V_e	effective volume	3 300 000	mm^3
l_e	effective length	1060	mm
A_e	effective area	3100	mm^2
	mass	≈19 000	g

Ferrite for particle accelerators RC500/300/25



Dimensions in mm.

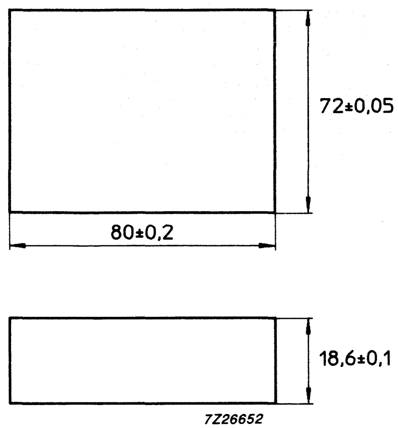
Fig.1 Ring core RC500/300/25.

Effective core parameters

SYMBOL	PARAMETER	VALUE	UNIT
Σ(l/A)	core factor (C1)	0.49	mm^{-1}
V_e	effective volume	2 950 000	mm^3
l_e	effective length	1200	mm
A_e	effective area	2450	mm^2
	mass	≈16 000	g

GRADE	A_L (nH)	ORDERING CODE
4M2	≈350	4322 020 9304

Ferrite for particle accelerators BLK80/72/19



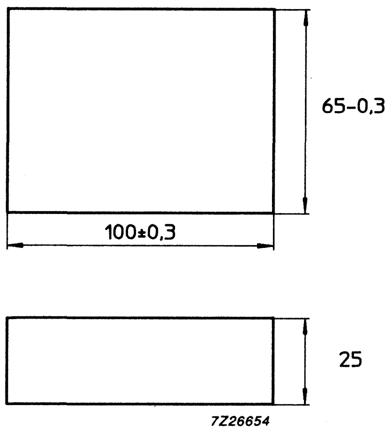
Dimensions in mm.

Fig.1 Block BLK80/72/19.

Mass: ≈550 g

GRADE	ORDERING CODE
8C11	4322 020 9878

Ferrite for particle accelerators BLK100/65/25



Dimensions in mm.

Fig.1 Block BLK100/65/25.

Mass: ≈800 g

GRADE	ORDERING CODE
8C11	4322 020 9893

MICROWAVE FERRITES

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

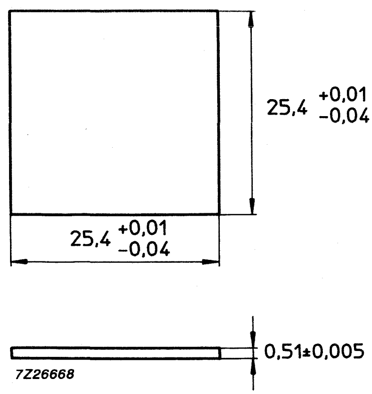
Isolators and circulators are key components in microwave technology. Isolators are used to separate an amplifier from its load, to avoid possible damage by reflected power. Circulators make it possible for transmitters to share the same antenna, or to use an antenna for simultaneous transmission and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

Our product range

We offer microwave ferrite grades 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.

SYMBOL	PARAMETER	CONDITIONS			5G1	5G8	UNIT
		FREQUENCY (MHz)	FIELD STRENGTH (A/m)	TEMP. (°C)			
J_S	saturation polarization		8×10^5	25 ±5	178 ±9	182.5 ±9	mT
ΔH	line width	9600			2200 ±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 $\delta_{(\varepsilon)}$	dielectric loss factor	9600			$<2 \times 10^{-4}$	$<3 \times 10^{-4}$	
ε'	dielectric constant				15.5 ±0.5	15.3 ±0.75	
	temperature coefficient of J_S		8×10^5	0 - 25 25 - 60	–0.36	–0.61	mT/K
g	Landé factor			25 ±5	2.00	2.00	
B_r	remanence		800		120	102	mT
B_s	saturation flux density		800		145		mT
T_C	Curie temperature				240	230	°C
ρ	resistivity			25 ±5	$>10^4$	$>10^8$	Ωm
	density				5140	5210	kg/m^3

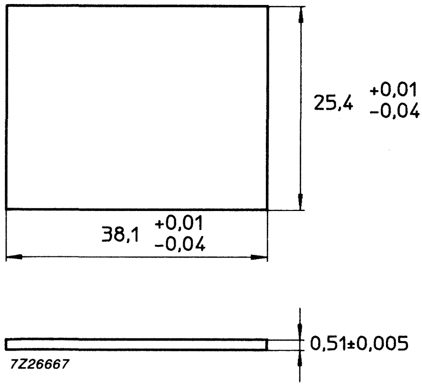
Mass: ≈1.6 g



Dimensions in mm.

Fig.1 Plate, PLT25/25/0.5.

GRADE	ORDERING CODE
5G1	4322 020 6510



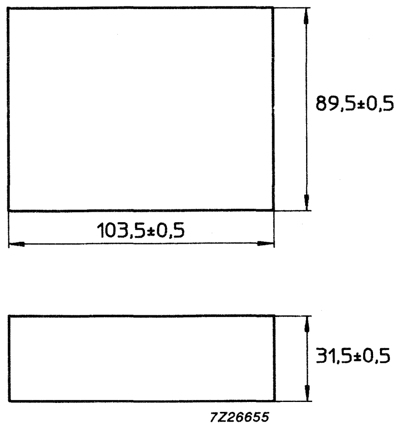
Dimensions in mm.

Fig.1 Plate, PLT38/25/0.5.

Mass: ≈2.4 g

GRADE	ORDERING CODE
5G1	4322 020 6511

Mass: ≈1500 g

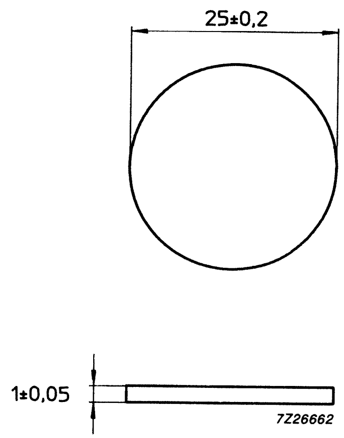


Dimensions in mm.

Fig.1 Block, BLK104/90/32.

GRADE	ORDERING CODE
5G1	4322 020 9416

Microwave ferrites | DSC25/1



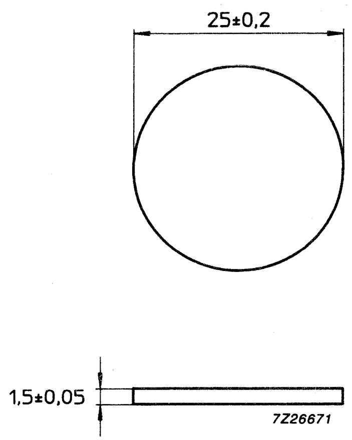
Dimensions in mm.

Fig.1 Disc, DSC25/1.

Mass: ≈2.5 g

GRADE	ORDERING CODE
5G8	4322 020 9269

Microwave ferrites DSC25/1.5



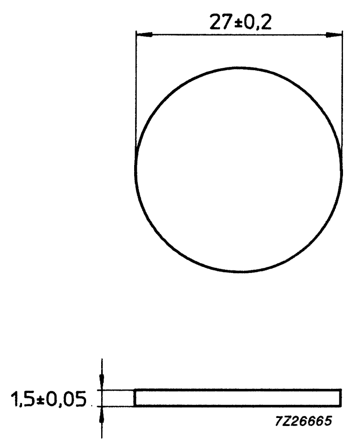
Dimensions in mm.

Fig.1 Disc, DSC25/1.5.

Mass: ≈3.8 g

GRADE	ORDERING CODE
5G1	4322 020 9268

Microwave ferrites DSC27/1.5



Dimensions in mm.

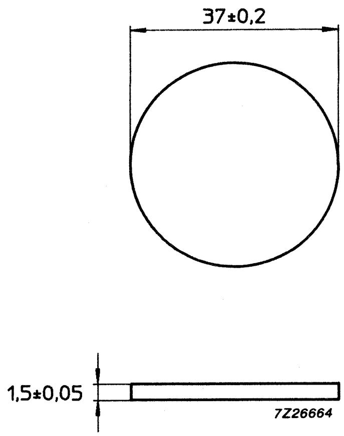
Fig.1 Disc, DSC27/1.5.

Mass: ≈4.5 g

GRADE	ORDERING CODE
5G1	4322 020 9271

DSC37/1.5

Mass: ≈8.2 g

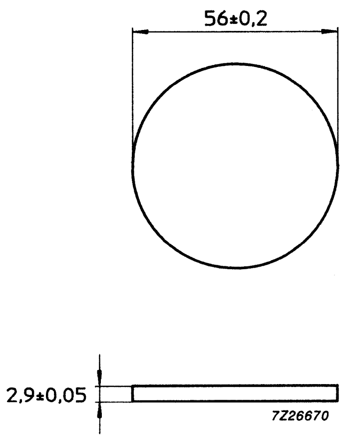


Dimensions in mm.

Fig.1 Disc, DSC 37/1.5.

GRADE	ORDERING CODE
5G1	4322 020 9272

Mass: ≈36 g

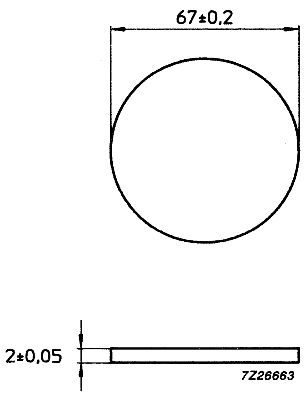


Dimensions in mm.

Fig.1 Disc, DSC56/2.9.

GRADE	ORDERING CODE
5G1	4322 020 3009

Microwave ferrites DSC67/2



Dimensions in mm.

Fig.1 Disc, DSC67/2.

Mass: ≈36 g

GRADE	ORDERING CODE
5G1	4322 020 9274

FERRITES FOR ELECTROMAGNETIC SHIELDING AND ABSORPTION

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. To check the behaviour of the equipment before bringing it on the market, controlled measurements must be carried out.

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 insulations 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.

- 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.

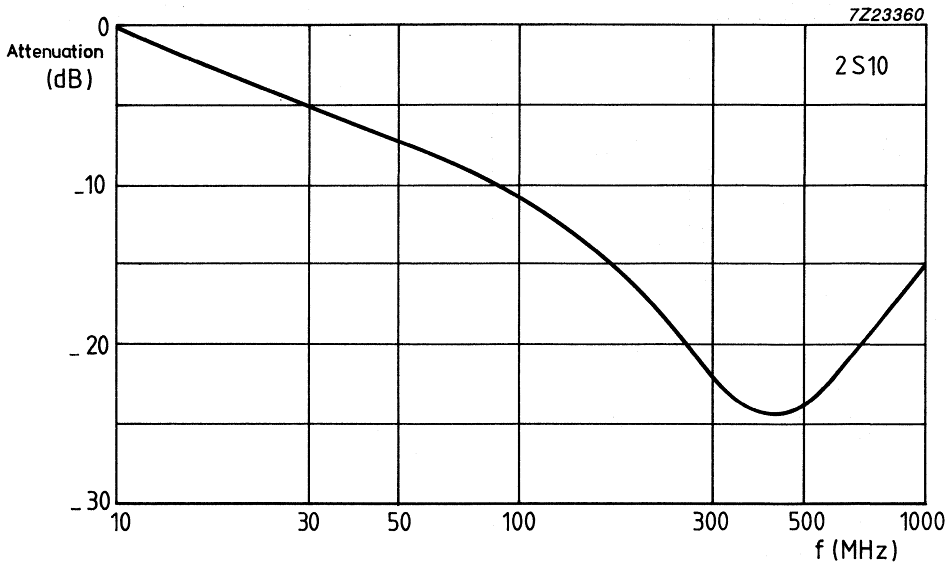


Fig.1 The reflectivity of metal-backed 2S10 plates.

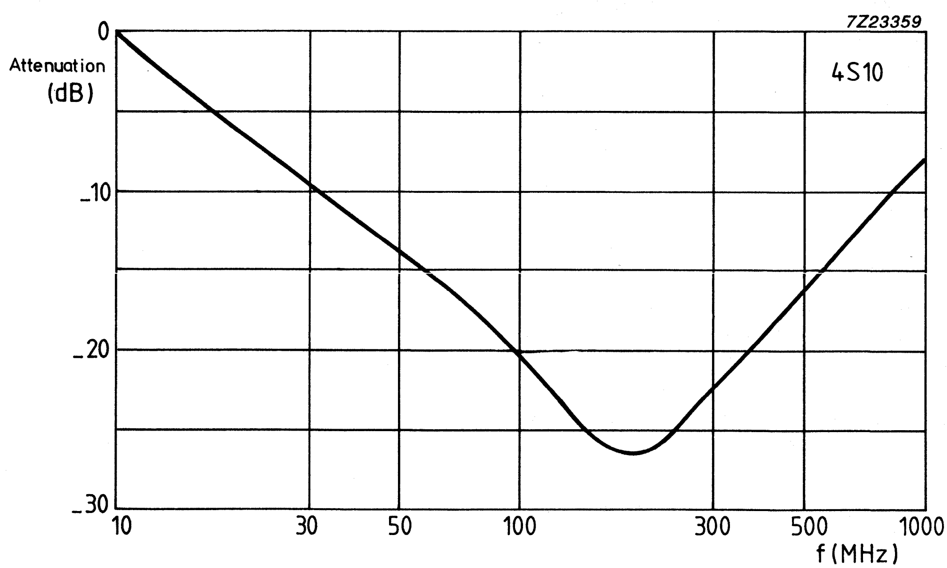
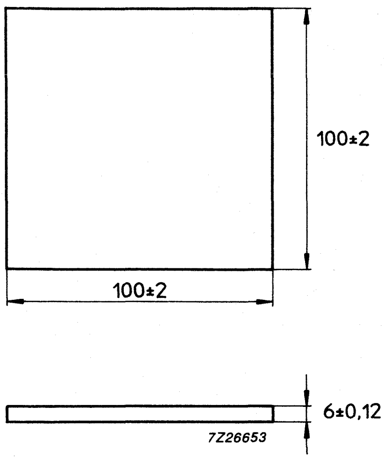


Fig.2 The reflectivity of metal-backed 4S10 plates.

Ferrites for EMC products PLT100/100/6



Dimensions in mm.

Fig.1 Plate, PLT100/100/6.

Mass: ≈300 g

GRADE	FREQUENCY RANGE (MHz)	ORDERING CODE
2S10	100 - 1000 MHz	4322 020 9933
4S10	30 - 1000 MHz	4322 020 9934

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 no objection, or if the powder is to be milled into the binder anyway.

GRADE	PARTICLE SIZE (µm)	ORDERING CODE
2S10	<200	4322 020 6936
4S10	<200	4322 020 6937
4S50	<200	4322 020 6938
PFP10	<200	4322 020 6939

FINE POWDERS

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

GRADE	PARTICLE SIZE (µm)	ORDERING CODE
2S10	<10	4322 020 6940
4S10	<10	4322 020 6941
4S50	<10	4322 020 6942
PFP10	<10	4322 020 6943

MAGNETIC HEADS

Magnetic heads are devices that can read and write on 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.
Magnetical and mechanical characteristics of MnZn single-crystal ferrites depend on the direction of orientation of the crystal.
Please consult us for detailed information.

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 approx. 2 x 2 x 10 mm and is determined by: $\Delta L/L_{20}$ (T-20).

	FREQ. (kHz)	B (mT)	H (A/m)	TEMP (°C)	8E1	8E2	8E21	8X1	UNITS
μ_i	≥10	<0.1		25	3200	2800	3600	1800 (note 1)	
B_s	ballistic		250	25	400	490	490	490	mT
$\frac{\tan\delta}{\mu_i}$	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 85	40 60	40 60	20 20		KW/m^3 KW/m^3
Curie temperature	4	<0.1			180	180	210	180	°C
resistivity	D.C			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. μ_i typ. 600 at 5 MHz measured on ring core 9/5/0.2 mm.

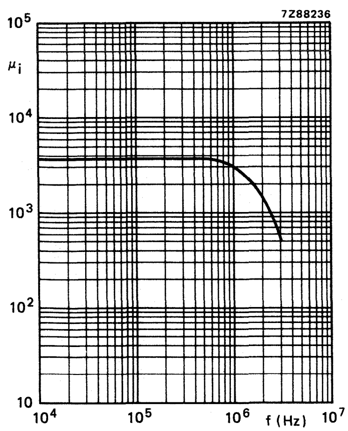


Fig.1 Initial permeability as a function of frequency.

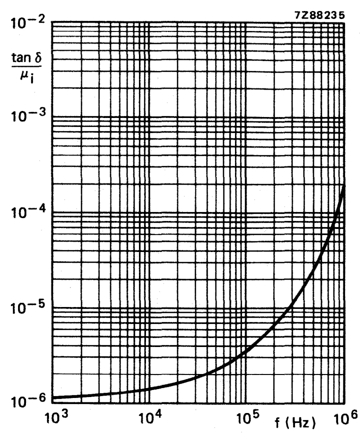


Fig.2 $\tan\delta/\mu_i$ as a function of frequency.

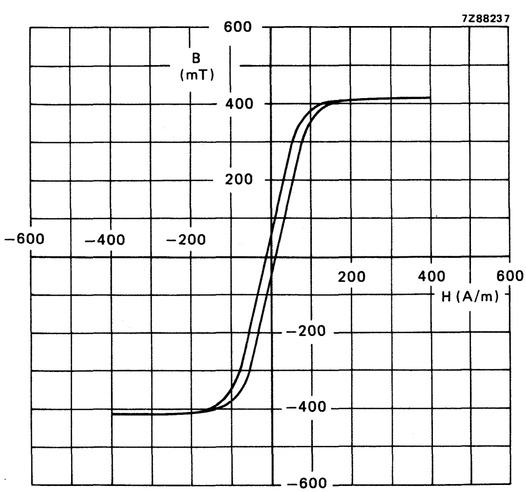


Fig.3 B-H-loop.

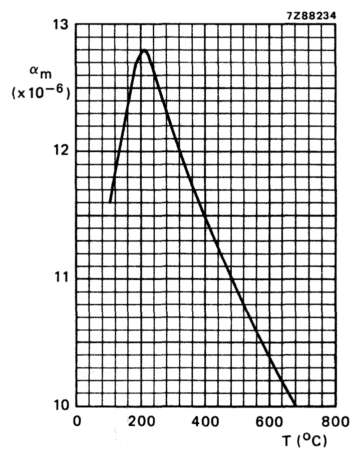


Fig.4 Coefficient of linear expansion as a function of temperature.

Material grade specification 8E2

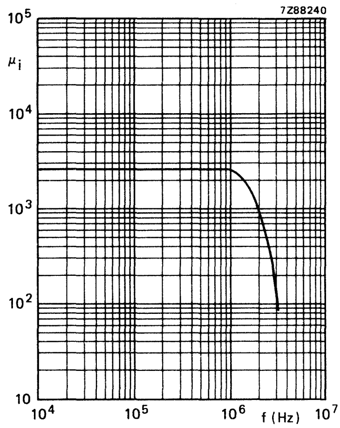


Fig.1 Initial permeability as a function of frequency.

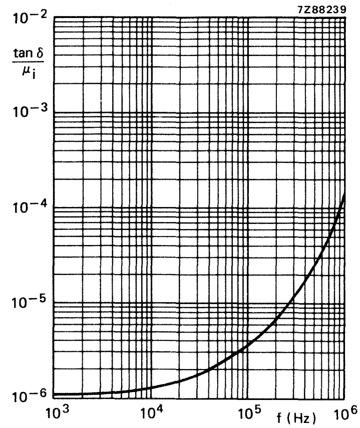


Fig.2 $\tan\delta/\mu_i$ as a function of frequency.

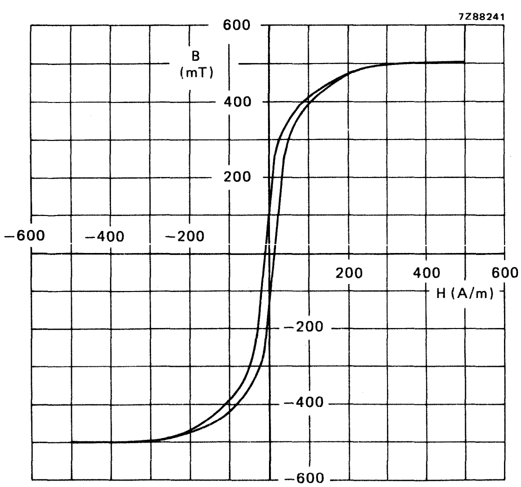


Fig.3 B-H-loop.

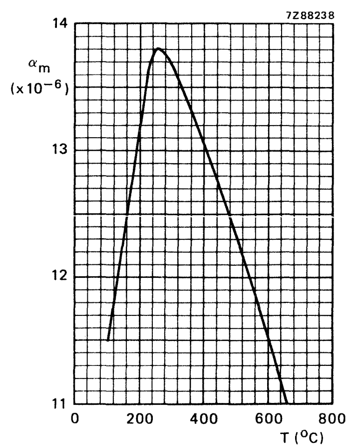
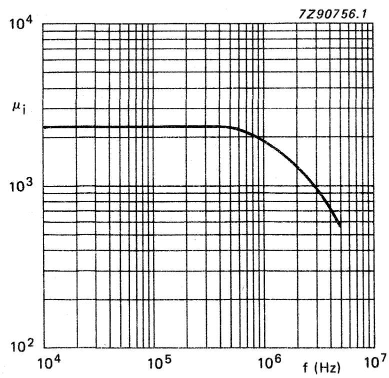


Fig.4 Coefficient of linear expansion as a function of temperature.



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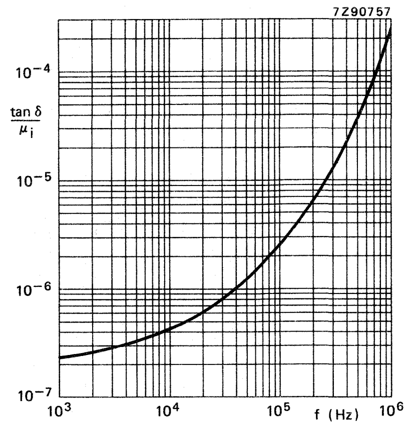


Fig.2 $\tan\delta/\mu_i$ as a function of frequency.

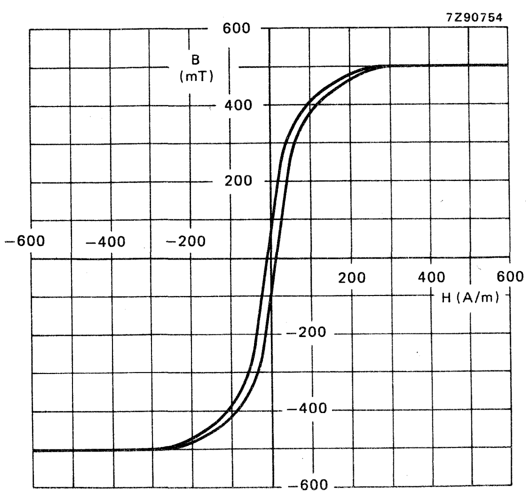


Fig.3 B-H-loop.

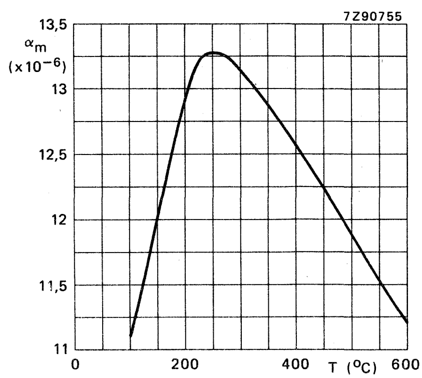


Fig.4 Coefficient of linear expansion as a function of temperature.

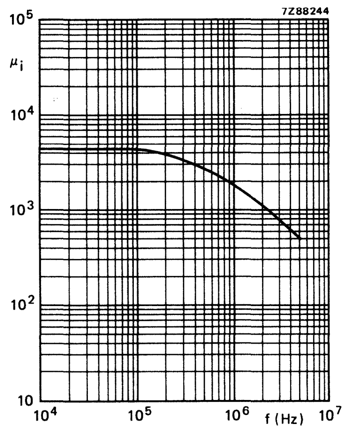


Fig.1 Initial permeability as a function of frequency.

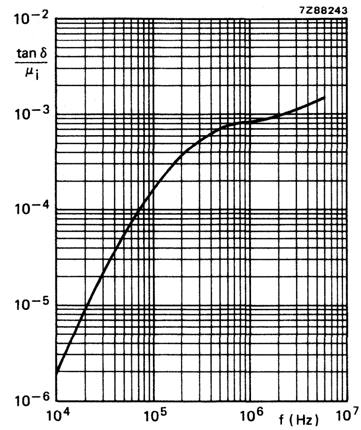


Fig.2 $\tan\delta/\mu_i$ as a function of frequency.

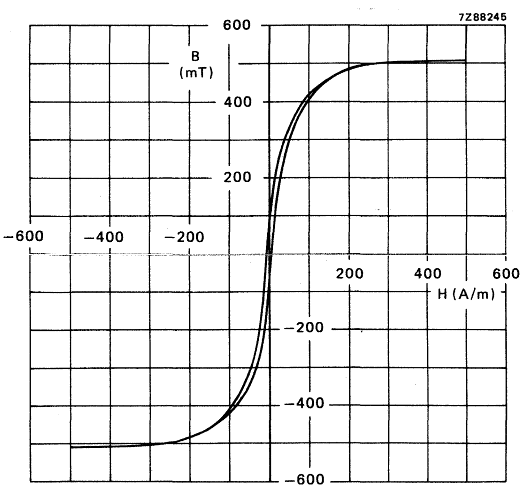


Fig.3 B-H-loop.

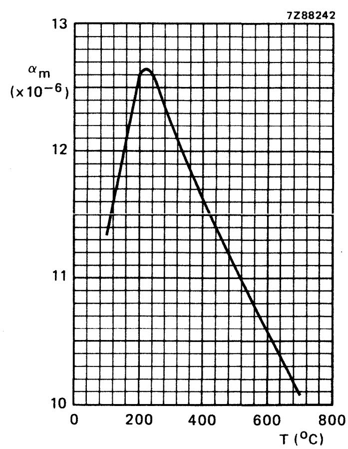
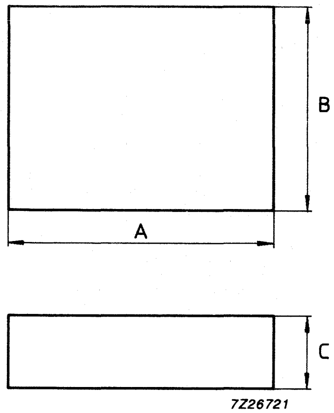


Fig.4 Coefficient of linear expansion as a function of temperature.

Ferrites for magnetic recording

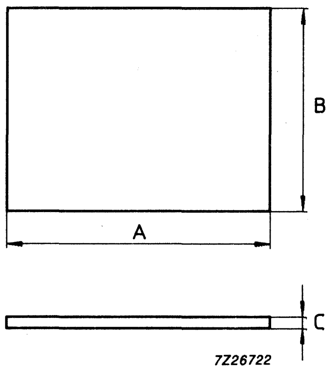
Bars



Dimensions in mm.

Fig.1 Bar.

A	B	C	GRADE	ORDERING CODE
100	28	12.5	8E1	4322 020 3740
100	35	7.8	8E2	4322 020 9750
100	35	12.5	8E1	4322 020 3748
100	35	14	8E1	4322 020 3747
100	49	14	8E1	4322 020 3746
215	39	26	8E21	4322 020 9768



Dimensions in mm.

Fig.1 Single-crystal plate.

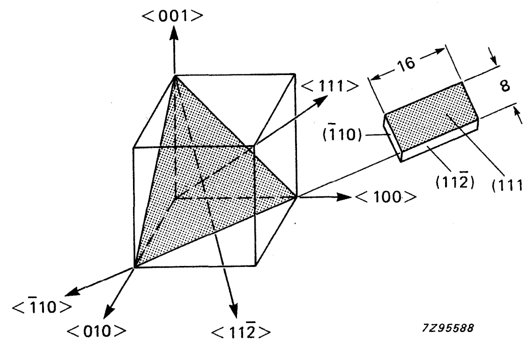


Fig.2 Orientation of single-crystal plates.

A	B	C	GRADE	ORIENTATION	ORDERING CODE
16	8	1.52	8X1	111	4322 020 9769

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DATA HANDBOOK SYSTEM

Data handbook system

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Our data handbook system comprises more than 65 books with subjects including electronic components, subassemblies and magnetic products. The handbooks are classified into seven series:

- INTEGRATED CIRCUITS;
- DISCRETE SEMICONDUCTORS;
- DISPLAY COMPONENTS;
- PASSIVE COMPONENTS;
- PROFESSIONAL COMPONENTS;
- MAGNETIC PRODUCTS;
- LIQUID CRYSTAL DISPLAYS.

Data handbooks contain all pertinent data available at the time of publication and each is revised and reissued regularly.

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

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