PHILIPS

Data handbook

PHILIPS

Electronic
components
and materials

Components and materials

Part 19 1984

Piezoelectric ceramics

PIEZOELECTRIC CERAMICS

DATA HANDBOOK SYSTEM

Our Data Handbook System is a comprehensive source of information on electronic components, subassemblies and materials; it is made up of four series of handbooks each comprising several parts.

ELECTRON TUBES	BLUE
SEMICONDUCTORS	RED
INTEGRATED CIRCUITS	PURPLE
COMPONENTS AND MATERIALS	GREEN

The several parts contain all pertinent data available at the time of publication, and each is revised and reissued periodically.

Where ratings or specifications differ from those published in the preceding edition they are pointed out by arrows. Where application information is given it is advisory and does not form part of the product specification.

If you need confirmation that the published data about any of our products are the latest available, please contact our representative. He is at your service and will be glad to answer your inquiries.

ELECTRON TUBES (BLUE SERIES)

The blue series of data handbooks is comprised of the following parts:

T1 **Tubes for r.f. heating**

T2a **Transmitting tubes for communications, glass types**

T2b **Transmitting tubes for communications, ceramic types**

T3 **Klystrons, travelling-wave tubes, microwave diodes**

ET3 **Special Quality tubes, miscellaneous devices** (will not be reprinted)

T4 **Magnetrons**

T5 **Cathode-ray tubes**
Instrument tubes, monitor and display tubes, C.R. tubes for special applications

T6 **Geiger-Müller tubes**

T7 **Gas-filled tubes**
Segment indicator tubes, indicator tubes, dry reed contact units, thyratrons, industrial rectifying tubes, ignitrons, high-voltage rectifying tubes, associated accessories

T8 **Picture tubes and components**
Colour TV picture tubes, black and white TV picture tubes, colour monitor tubes for data graphic display, monochrome monitor tubes for data graphic display, components for colour television, components for black and white television and monochrome data graphic display

T9 **Photo and electron multipliers**
Photomultiplier tubes, phototubes, single channel electron multipliers, channel electron multiplier plates

T10 **Camera tubes and accessories**

T11 **Microwave semiconductors and components**

T12 **Vidicons and Newvicons**

T13 **Image intensifiers**

T14 **Infrared detectors**

SEMICONDUCTORS (RED SERIES)

The red series of data handbooks is comprised of the following parts:

S1 **Diodes**
Small-signal germanium diodes, small-signal silicon diodes, voltage regulator diodes(< 1,5 W), voltage reference diodes, tuner diodes, rectifier diodes

S2 **Power diodes, thyristors, triacs**
Rectifier diodes, voltage regulator diodes (> 1,5 W), rectifier stacks, thyristors, triacs

S3 **Small-signal transistors**

S4a **Low-frequency power transistors and hybrid modules**

S4b **High-voltage and switching power transistors**

S5 **Field-effect transistors**

S6 **R.F. power transistors and modules**

S7 **Microminiature semiconductors for hybrid circuits**

S8 **Devices for optoelectronics**
Photosensitive diodes and transistors, light-emitting diodes, displays, photocouplers, infrared sensitive devices, photoconductive devices.

S9 **Power MOS transistors**

S10 **Wideband transistors and wideband hybrid IC modules**

INTEGRATED CIRCUITS (PURPLE SERIES)

The purple series of data handbooks is comprised of the following parts:

IC1 **Bipolar ICs for radio and audio equipment**

IC2 **Bipolar ICs for video equipment**

IC3 **ICs for digital systems in radio, audio and video equipment**

IC4 **Digital integrated circuits**
CMOS HE4000B family

IC5 **Digital integrated circuits — ECL**
ECL10 000 (GX family), ECL100 000 (HX family), dedicated designs

IC6 **Professional analogue integrated circuits**

IC7 **Signetics bipolar memories**

IC8 **Signetics analogue circuits**

IC9 **Signetics TTL logic**

IC10 **Signetics Integrated Fuse Logic (IFL)**

IC11 **Microprocessors, microcomputers and peripheral circuitry**

COMPONENTS AND MATERIALS (GREEN SERIES)

The green series of data handbooks is comprised of the following parts:

C1 **Assemblies for industrial use**
PLC modules, PC20 modules, HNIL FZ/30 series, NORbits 60-, 61-, 90-series, input devices, hybrid ICs

C2 **Television tuners, video modulators, surface acoustic wave filters**

C3 **Loudspeakers**

C4 **Ferroxcube potcores, square cores and cross cores**

C5 **Ferroxcube for power, audio/video and accelerators**

C6 **Synchronous motors and gearboxes**

C7 **Variable capacitors**

C8 **Variable mains transformers**

C9 **Piezoelectric quartz devices**
Quartz crystal units, temperature compensated crystal oscillators, compact integrated oscillators, quartz crystal cuts for temperature measurements

C10 **Connectors**

C11 **Non-linear resistors**
Voltage dependent resistors (VDR), light dependent resistors (LDR), negative temperature coefficient thermistors (NTC), positive temperature coefficient thermistors (PTC)

C12 **Variable resistors and test switches**

C13 **Fixed resistors**

C14 **Electrolytic and solid capacitors**

C15 **Film capacitors, ceramic capacitors**

C16 **Permanent magnet materials**

C17 **Stepping motors and associated electronics**

C18 **D.C. motors**

C19 **Piezoelectric ceramics**

Description of Symbols

ϵ_o	= dielectric constant of free space = 8,85 x 10^{-12} farads/metre.
ϵ^T/ϵ_o	= relative dielectric constant, free.
ϵ^S/ϵ_o	= relative dielectric, clamped
$\tan\delta = \frac{1}{Q_E}$	= dissipation factor at 1 kHz, low electric field.
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_m^E	= mechanical quality factor radial mode.
N_1	= frequency constant.

INTRODUCTION

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* and is a thermodynamic consequence of the direct 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.

Besides the crystals mentioned above, an important group of piezoelectric materials are the piezoelectric ceramics, of which PXE 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.

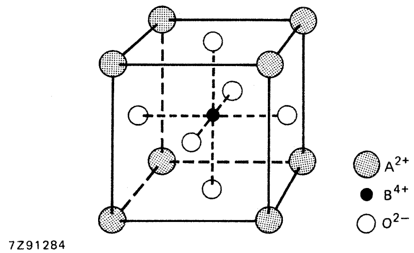


Fig. 1.

PXE can be fashioned into components of almost any shape and size. And 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. They are available in several grades distinguished by their electrical and physical properties to meet particular requirements.

THE 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 fired, 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 *remanent* 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.

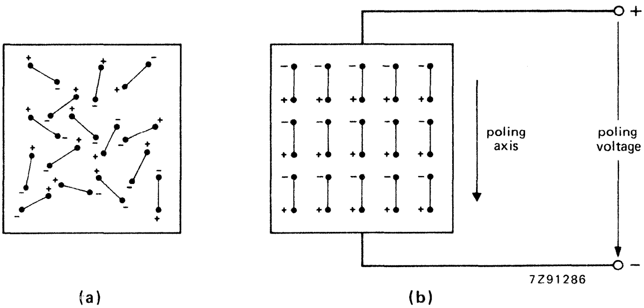


Fig. 2 Electric dipoles (of the domain) in piezoelectric materials (a) before and (b) after polarization (ideal conditions).

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 crystalline.

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.

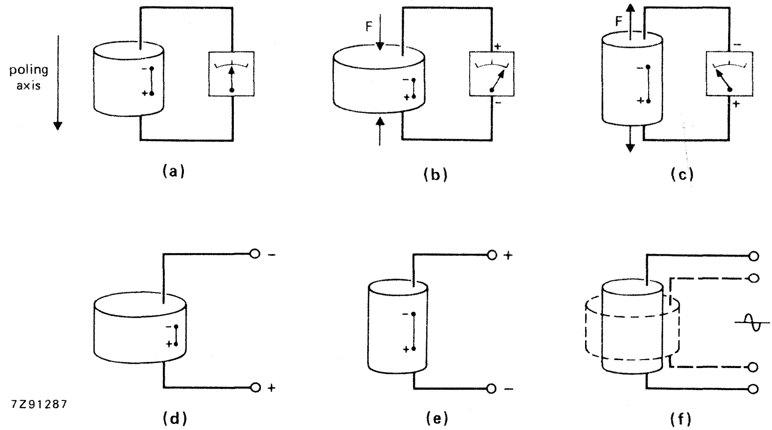


Fig. 3 The piezoelectric effect on a cylindrical body of piezoelectric ceramic. For the sake of clarity only one dipole is shown.

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 voltage, 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. These are examples of *motor action* – conversion of electrical energy into mechanical energy. PXE-induced motor action is found in transducers for ultrasonic cleaning equipment, ultrasonic atomizers and fuel injection systems.

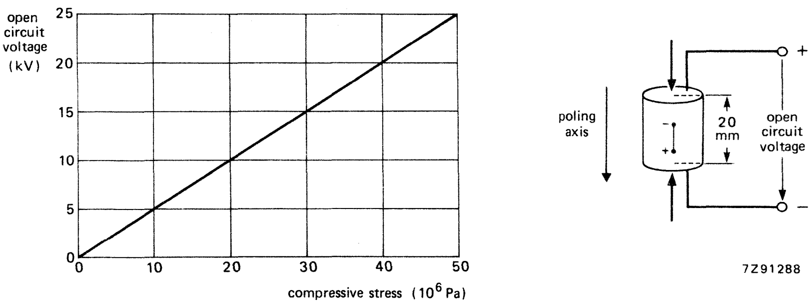


Fig. 4 Open circuit voltage of a 20 mm long piezoelectric ceramic cylinder as a function of compressive stress applied.

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.

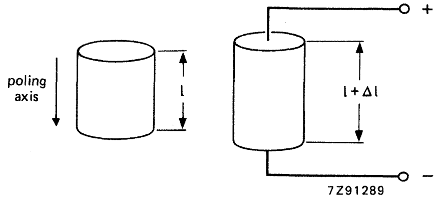


Fig. 5 Elongation of a cylindrical piezoelectric ceramic body caused by a d.c. voltage.

The maximum piezoelectric-induced strain, Δl/l (Fig. 5), in a PXE cylinder (PXE 5) is around $1,6 \times 10^{-4}$ — corresponding to a maximum electric field strength of 450 V/mm. In a 20 mm cylinder, this would produce an extension of about 3,3 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 3,3 μm maximum static displacement.

PIEZOELECTRIC RELATIONSHIPS

Direct piezoelectric effect

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

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

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

In terms of the electric field E and electric displacement D, the polarization of a dielectric is

$$P = D - \epsilon E \qquad (2)$$

in which ϵ is the permitivity, itself a stress dependent quantity. To a first approximation, this dependence can be neglected and (1) and (2) combined to give $dT = D - \epsilon^T E$, or

$$D = dT + \epsilon^T E \qquad (3)$$

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

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

where $g = d/\epsilon^T$ is known as the: *piezoelectric charge 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 subject to an external electric field is given by

$$S = dE$$

or

$$S = gD.$$

The strain experienced by an elastic medium subject 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

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

or

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

in which s^E and s^D are respectively the specific compliances 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 $k = d^2/[s^E \epsilon^T]$ or $k^2/[1 - k^2] = g^2 \epsilon^T/s^D$.

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

$$k^2 = \left[\frac{\text{stored energy converted}}{\text{stored input energy}}\right]$$

k is referred to as the: *coupling factor.*

This formula holds for both electro-mechanical and mechano-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 k^2 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.

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, permitivity 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, 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 below, 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.

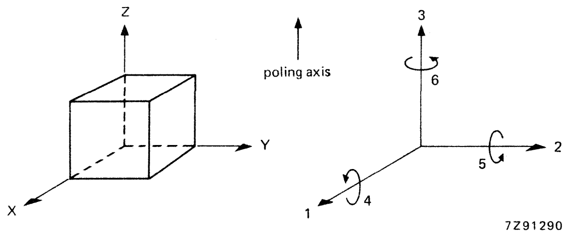


Fig. 6.

Permittivity ϵ

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

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

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

The table of principal properties gives the relative permittivity, i.e. ϵ/ϵ_0 (ϵ is the absolute permittivity, ϵ_0 the permittivity of vacuum = 8,85 x 10^{-12} farad/metre).

Compliance s, modulus of elasticity Y (= 1/s)

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

$s_{33}^{E} = 1/Y_{33}^{E}$ is the strain per unit stress in the 3-direction at constant electric field.

$s_{55}^{D} = 1/Y_{55}^{D}$ 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

k_{31} in the coupling factor 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. 7); hence the term radial coupling ($k_r = k_p$).

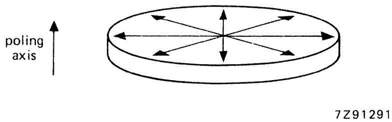


Fig. 7.

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.

Frequency constant N

The frequency constant is the product of a resonant frequency and the linear dimension governing the resonance. If the applied electric field is perpendicular to the direction of vibration, then the resonance is the series resonance. If the field is parallel, then it is the parallel resonant frequency. Thus, for a 31 or 15 mode resonance and for the planar or radial mode resonance, the relevant frequency constants are N_1^E, N_5^E, and N_p^E. On the other hand, for 33 mode resonance, the frequency constant is N_3^D. Thus N_1^E, N_5^E, and N_p^E give the minimum impedance, or series resonant frequency, whilst N_3^D gives the maximum impedance, or parallel resonant frequency. If one wants to determine the length of a 33 resonator for a certain series resonant frequency, the equivalent parallel resonant frequency should first be determined, using the coupling coefficient k_{33}. The resonant length can be determined using N_3^D and the parallel resonant frequency.

The frequency constant for longitudinal vibration of a long bar poled lengthwise is usually denoted by N_3^D. However, the frequency constant for extensional thickness vibration of a thin disc with arbitrary contour poled in the thickness direction, is usually denoted by N_t^D. For a disc, both N_t^D and N_p^E are of interest. The frequency constants are equal to half the governing sound velocity in the ceramic body, except for the constant N_p^E. Thus $N^D = \frac{1}{2}\,(s^D \rho_m)^{-\frac{1}{2}}$ and $N^E = \frac{1}{2}\,(s^E \rho_m)^{-\frac{1}{2}}$, where $s^D = s^E\,(1 - k^2)$, ρ_m = mass density, and the various constants have appropriate subscripts.

DYNAMIC BEHAVIOUR

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

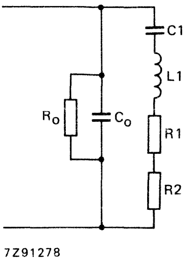


Fig. 8.

C_o = capacitance of the clamped transducer.

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

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.

If the electrical admittance (Y) of the vibrating transducer is plotted against the frequency, one obtains the following resonant curve. (Fig. 9).

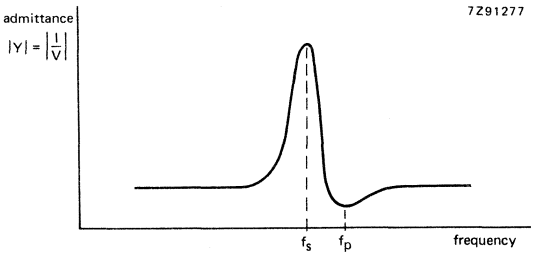


Fig. 9.

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.

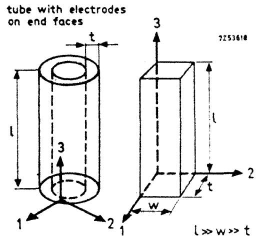
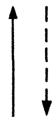
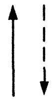
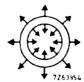
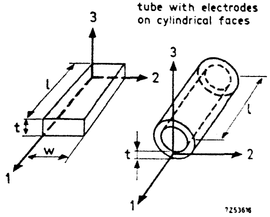
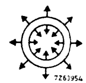
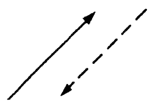
DEPOLARIZATION

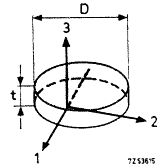
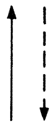
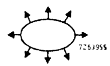
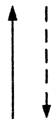
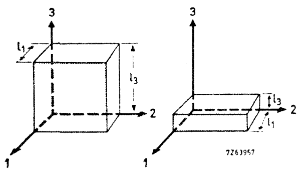
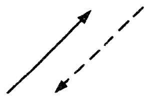
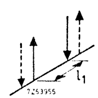
The polarization (poling) of piezoelectric materials is permanent. However, when working with these materials, the following points should be borne in mind:

(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.

MODES OF VIBRATION

resonant element with electrodes	biasing polarization	a.c. field and polarization	main component of a.c. stress and strain	conditions satisfied	pertinent coupling factor and frequency constant vibrational mode
		 E_3, D_3	 T_3, S_3 (axial direction in tube)	$S_1 = S_2 = 0$ $T_1 = T_2 = 0$	$(k_{33})T_1T_2 = k_{33}$ $(N_3^E)T_1T_2 = N_3 = f_1l$ length mode with parallel excitation
			parallelepiped  T_1, S_1  **tube** *T* and *S* in radial direction	$S_2 = S_3 = 0$ $T_2 = T_3 = 0$	$(k_{31})S_2S_3 = k_{31}^*$ $(N_1^E)S_2S_3 = N_1^* = f_rt$ thickness mode with transverse excitation
		 E_3, D_3	 **tube** *T* and *S* in radial direction **parallelepiped**  T_3, S_3	$S_1 = S_2 = 0$ $T_1 = T_3 = 0$	$(k_{33})S_1S_2 = k_t$ $(N_3^E)S_1S_2 = N_t = f_rt$ thickness mode with parallel excitation
			 T_1, S_1 (axial direction in tube)	$S_2 = S_3 = 0$ $T_2 = T_3 = 0$	$(k_{31})T_2T_3 = k_{31}$ $(N_1^E)T_2T_3 = N_1 = f_rl$ length mode with transverse excitation

		 E_3, D_3	 T_1, S_1 (radial direction) (also T_2, S_2 in circular direction)	$S_3 = 0$ $T_3 = 0$	$k_{31}\sqrt{2/(1-\sigma)} = k_p$ $N_p^E = N_p = P_r D$ planar mode with transverse excitation
			 T_3, S_3	$S_1 = S_2 = 0$ $T_1 = T_2 = 0$	$(k_{33})S_1S_2 = k_t$ $(N_3^E)S_1S_2 = N_t = f_r t$ thickness mode with parallel excitation
		 E_1, D_1	shear in 31-plane T_5, S_5 	propagation of shear waves in 1-direction if $l_1 = t \ll l_3$, in 3-direction if $l_3 = t \ll l_1$	k_5 $N_5^E = N_5 = f_r t$ thickness shear mode thickness t being l_1 or l_3 whichever is smaller

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 characteristics, 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 a 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 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 h.f. shear resonance applications where phase is important, e.g. in ultrasonic delay lines for colour television receivers.

PRINCIPAL PROPERTIES

The following grades, consisting of modified lead zirconate titanates are distinguished according to their electrical and mechanical properties and field of application.
Unless otherwise stated, the specified values are measured at 20 ± 5 °C, 24 h after poling.

property and symbol		unit	PXE 5	PXE 52
thermal data				
Curie temperature		°C	285	165
specific heat		J/kg K	420	420
thermal conductivity		W/m K	1,2	1,2
mechanical data				
density ρ_m		10^3 kg/m^3	7,7	7,8
compliance	s_{33}^E	10^{-12} /Pa	18	20
	s_{11}^E	10^{-12} /Pa	15	16
	s_{55}^E	10^{-12} /Pa	38,5	
Poisson's ratio σ			≈ 0,3	0,3
mechanical quality factor for radial mode Q_m^E			≈ 80	≈ 65
frequency constants	N_p^E	Hz m or m/s	2000	1950
	$N_3^D = \frac{1}{2} \nu_3^D$	Hz m or m/s	1850	1900
	$N_1^E = \frac{1}{2} \nu_1^E$	Hz m or m/s	1450	1400
	$N_5^E = \frac{1}{2} \nu_5^E$	Hz m or m/s	930	
compressive strength		10^6 Pa	> 600	> 600
tensile strength		10^6 Pa	≈ 80	≈ 80
electrical data				
relative permittivity	$\epsilon_{33}^T/\epsilon_0$		2000	3500
(ϵ_0 = 8,85.10^{-12} F/m)	$\epsilon_{11}^T/\epsilon_0$		1800	3000
resistivity ρ_{el} (25 °C)		10^{12} Ωm	1	
time constant $\rho_{el}\ \epsilon_{33}^T$ (25 °C)		min	> 300	> 500
dielectric loss factor tan δ		10^{-3}	20	16
electro-mechanical data				
coupling factor	k_p		0,63	0,65
	k_{33}		0,69	0,74
	k_{31}		0,37	0,39
	k_{15}		0,66	
piezoelectric charge constants	d_{33}	10^{-12} C/N or m/V	390	580
	d_{31}	10^{-12} C/N or m/V	− 190	− 270
	d_{15}	10^{-12} C/N or m/V	515	
piezoelectric voltage constants	g_{33}	10^{-3} Vm/N or m^2/C	22,0	19
	g_{31}	10^{-3} Vm/N or m^2/C	− 10,9	− 8,7
	g_{15}	10^{-3} Vm/N or m^2/C	32,5	
time stability				
coupling factor k_p		relative change per time decade (%)	− 0,5	− 0,6
permittivity ϵ_{33}^T		relative change per time decade (%)	−1,0	− 1,0
frequency constant N_p^E		relative change per time decade (%)	0,5	0,3
quality factor Q_m^E		relative change per time decade (%)		− 3
dielectric loss factor tan δ		relative change per time decade (%)		

The properties of components manufactured from PXE are dependent on the dimensions of the product and method of manufacture, and also on the measuring level. Therefore a meaningful interpretation of the properties of the material is best done in consultation with the supplier.

PXE 21	**PXE 41**	**PXE 42**	**PXE 43**	**PXE 71**
270	315	325	300	270
420	420	420	420	420
1,2	1,2	1,2	1,2	1,2
7,75	7,90	7,70	7,70	7,75
18,6	14,6	15,3	12,6	–
15,1	12,2	12,7	11,3	15,0
	37,0			38,0
≈ 0,3	≈ 0,3	≈ 0,3	0,3	≈ 0,3
≈ 80	≈ 1000	≈ 750	1000	≈ 80
2000	2200	2200	2350	2050
1900	2000	2015	2050	–
	1620			1500
	950			920
> 600	> 600	> 600	> 600	> 600
≈ 80	≈ 80	≈ 80	≈ 80	≈ 80
1750	1200	1300	1000	1300
	1400			1700
0,1	0,05			1
> 25	> 7			> 250
18	2,5	2,5	2	20
0,62	0,58	0,58	0,50	0,60
0,72	0,68	0,68	0,63	–
0,37	0,34	0,34	0,30	0,35
	0,70			0,66
385	268	285	210	–
– 180	– 119	– 130	–95	–147
	480			500
25,0	25,2	25,0	25,0	–
– 11,6	– 11,6	– 11,0	–10,7	–12,8
	38,5			33,2
– 1,5	– 1,5	– 2,5	– 2	– 0,5
– 2	1	– 6,0	– 4,5	– 0,5
0,5	0,5	1,5	1	0,5
	10			
	– 10			

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, atomization.
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.
Pick-ups and sensors:	record players, accelerometers, detection systems in machinery, e.g. textile, medical equipment, motor cars, e.g. knock 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.

CONNECTION

An electrical contact may be made by soldering bonding or clamping wires to the electrodes which can be metallized in silver or nickel.

SOLDERING

The electrode surface should be free from grease and dust. If tarnished, the silver should be lightly cleaned. Suggested soldering prescription:

- 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,
- 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 depending on temperature and time).

BONDING

Stranded wire may also be bonded to the electrode surface using a resin to give a good low resistance contact. Lacquered strands must of course be cleaned before bending and the strands should be splayed out and pressed on to the electrode surface while the epoxy resin is curing.

GENERAL NOTE

Where possible it is preferable to make electrical contact at the vibration mode in resonant devices. In some application a simple spring or pressure contact may be quite adequate.

QUALITY ASPECTS

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

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

inspection	A.Q.L.	inspection level
mechanical	1	I
electrical	0,65	II
visual	1	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.

STABILITY

The properties of piezoelectric elements are more or less temperature and time dependent. The stability, as a function of time, is of particular interest. Fortunately the poling ages approximately logarithmically (Figs 10 and 11), so that the rate of change in permittivity, coupling factor, frequency constant, and so on, reduces rapidly in the course of time. Powerful ambient influences are likely to change the original ageing pattern. This applies particularly to the permittivity, the mechanical quality factor, and the dielectric loss factor, tan δ.

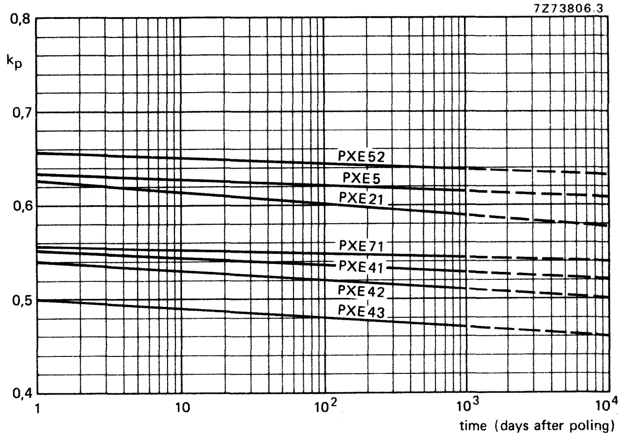


Fig. 10.

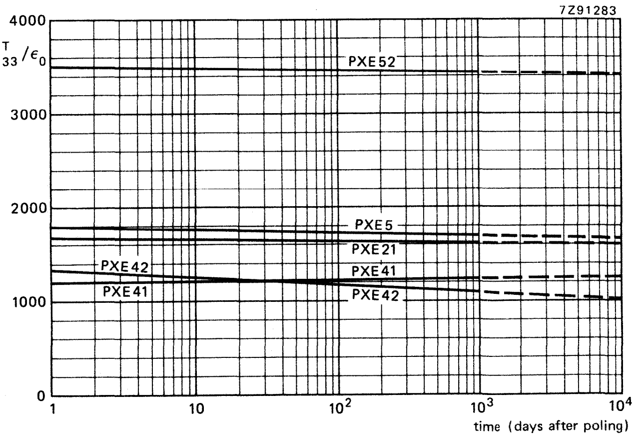
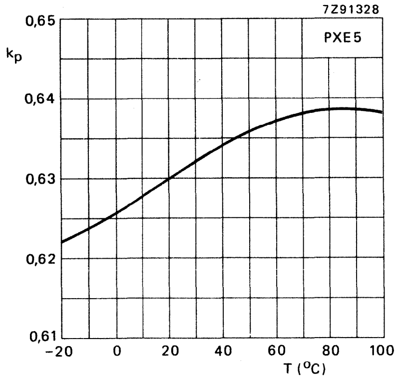
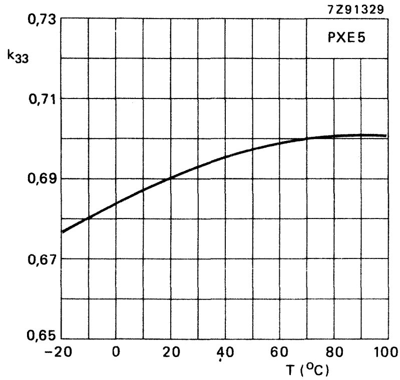
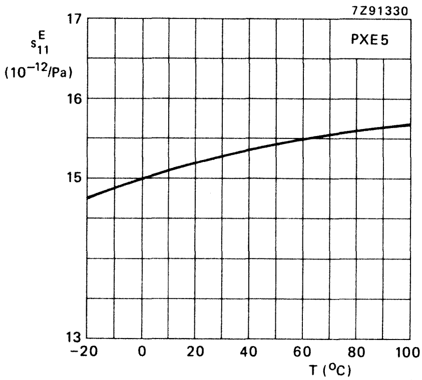


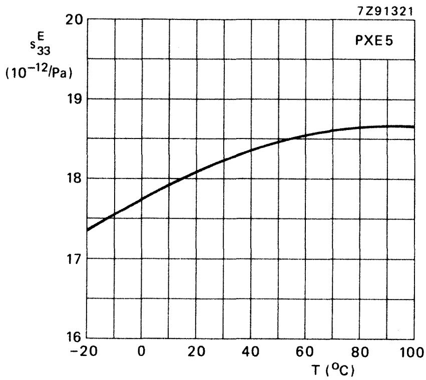
Fig. 11.

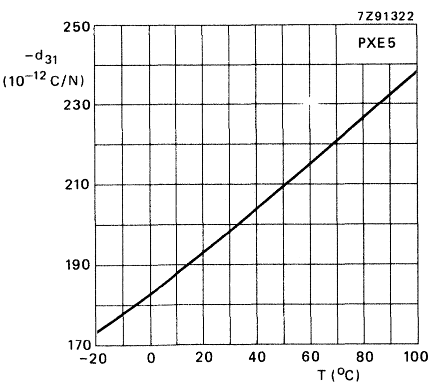
TEMPERATURE EFFECTS
PXE 5

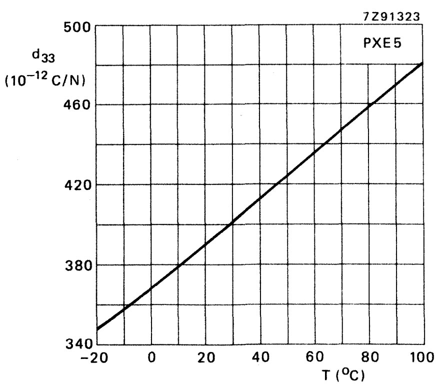


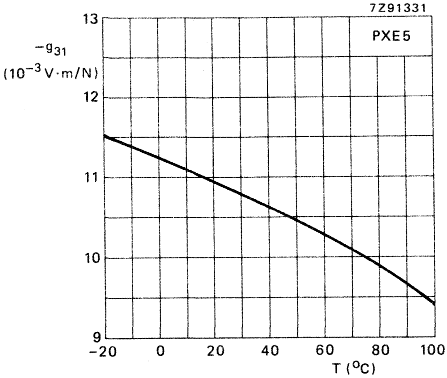


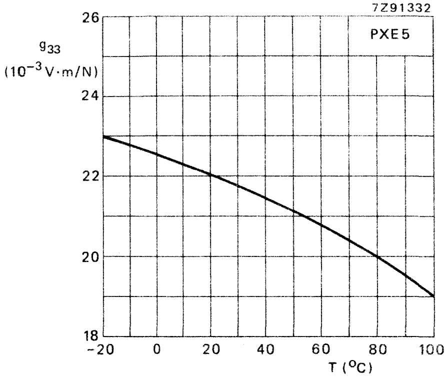


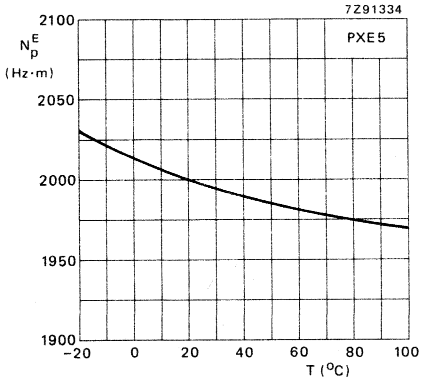


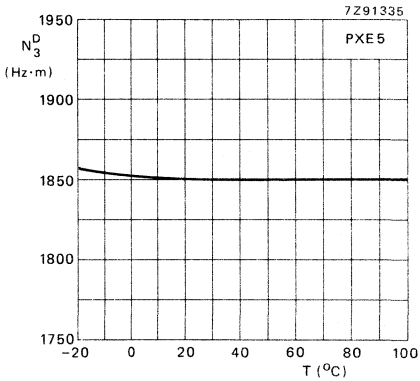


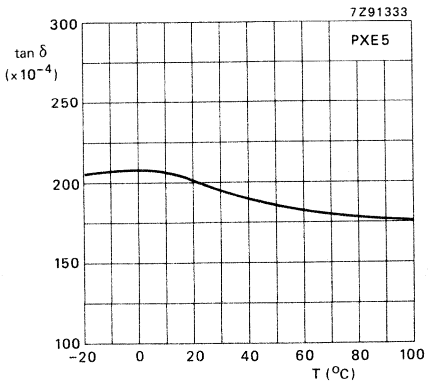


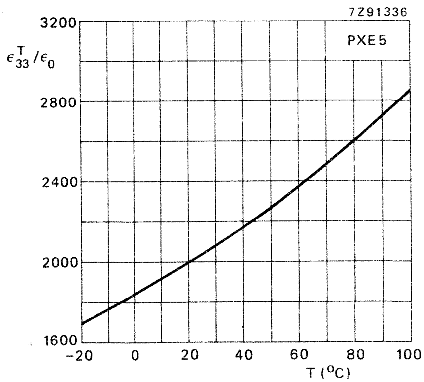

7Z91331
PXE5
$-g_{31}$
$(10^{-3}$ V·m/N)
13
12
11
10
9
−20
0
20
40
60
80
100
T (°C)


7Z91332
PXE5
g_{33}
$(10^{-3}$ V·m/N)
26
24
22
20
18
−20
0
20
40
60
80
100
T (°C)

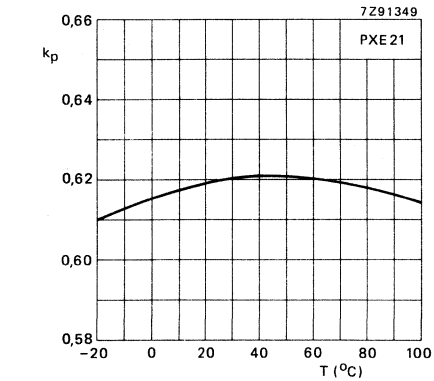

7Z91334
PXE5
N_p^E
(Hz·m)
2100
2050
2000
1950
1900
−20
0
20
40
60
80
100
T (°C)

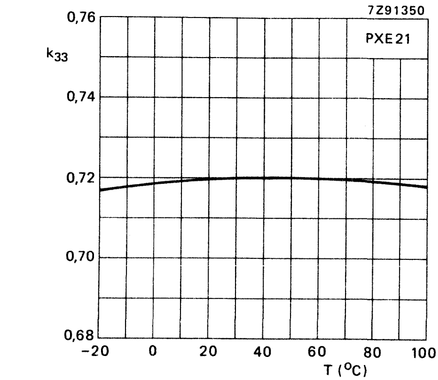

7Z91335
PXE5
N_3^D
(Hz·m)
1950
1900
1850
1800
1750
−20
0
20
40
60
80
100
T (°C)

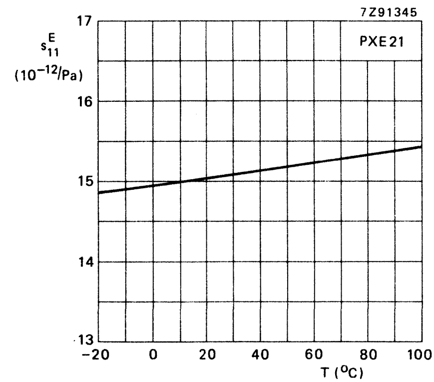

7Z91333
PXE5
tan δ
$(\times 10^{-4})$
300
250
200
150
100
−20
0
20
40
60
80
100
T (°C)

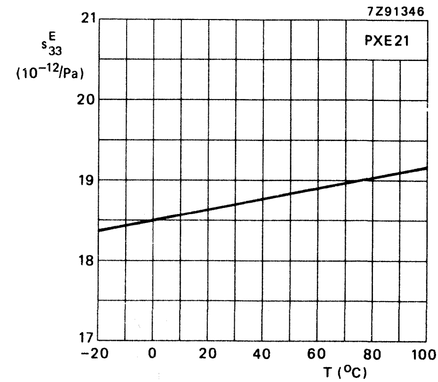

7Z91336
PXE5
$\epsilon_{33}^T/\epsilon_0$
3200
2800
2400
2000
1600
−20
0
20
40
60
80
100
T (°C)

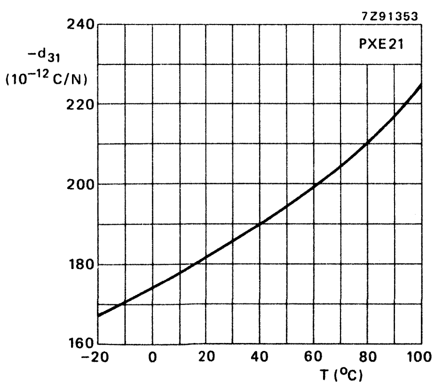
TEMPERATURE EFFECTS
PXE 21

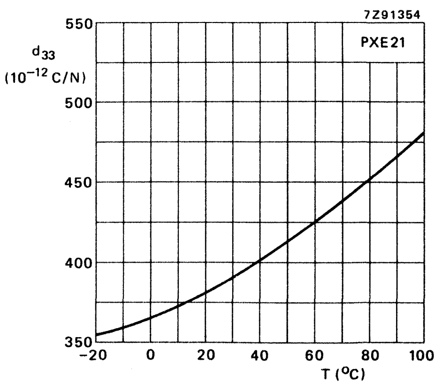


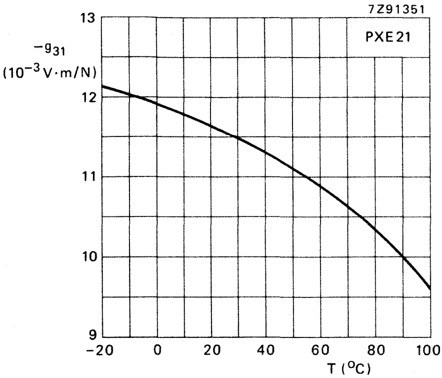


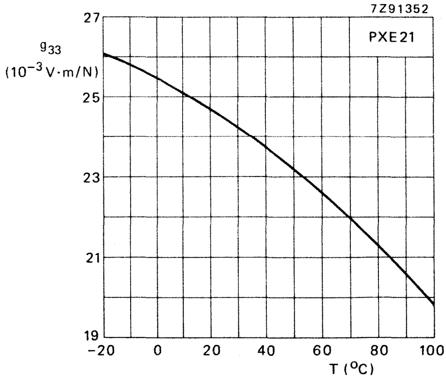


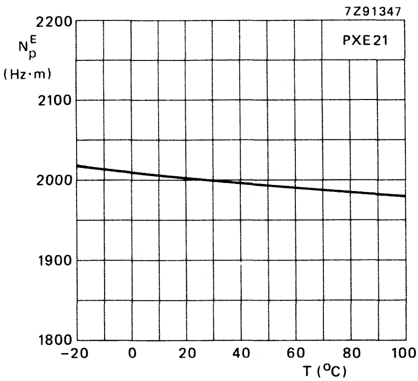


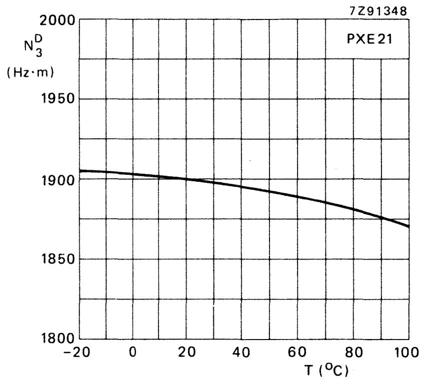


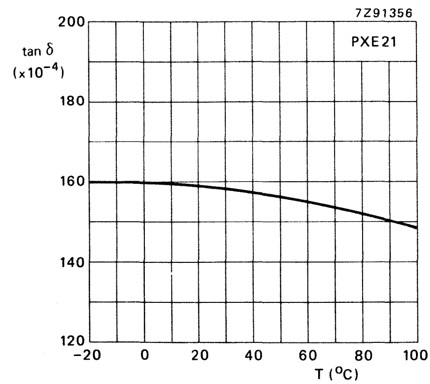


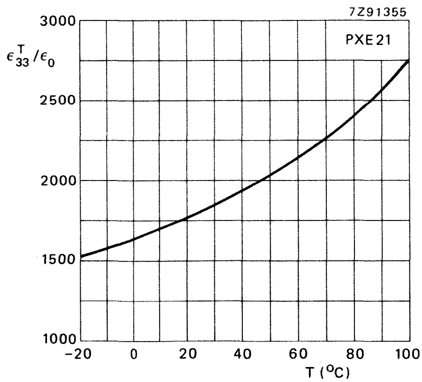

7Z91351
PXE 21
$-g_{31}$
(10^{-3} V·m/N)
13
12
11
10
9
−20
0
20
40
60
80
100
T (°C)


7Z91352
PXE 21
g_{33}
(10^{-3} V·m/N)
27
25
23
21
19
−20
0
20
40
60
80
100
T (°C)


7Z91347
PXE 21
N_p^E
(Hz·m)
2200
2100
2000
1900
1800
−20
0
20
40
60
80
100
T (°C)

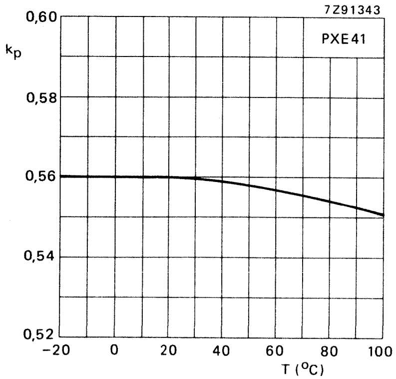

7Z91348
PXE 21
N_3^D
(Hz·m)
2000
1950
1900
1850
1800
−20
0
20
40
60
80
100
T (°C)

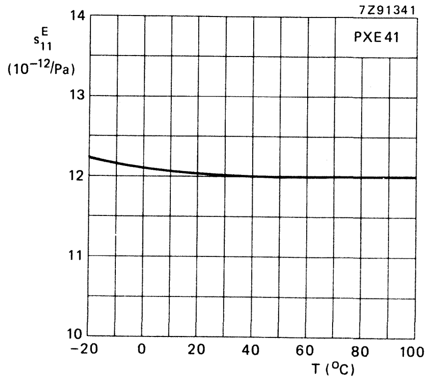

7Z91356
PXE 21
tan δ
(x10^{-4})
200
180
160
140
120
−20
0
20
40
60
80
100
T (°C)

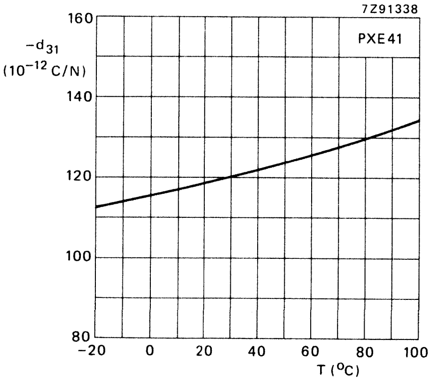

7Z91355
PXE 21
$\epsilon_{33}^T/\epsilon_0$
3000
2500
2000
1500
1000
−20
0
20
40
60
80
100
T (°C)

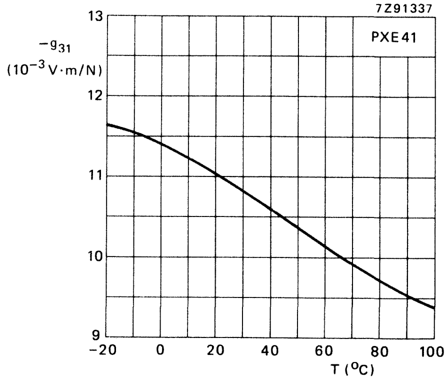
TEMPERATURE EFFECTS

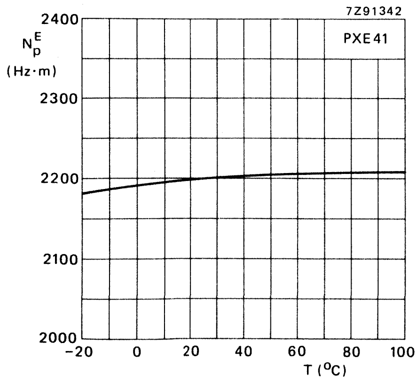
PXE 41

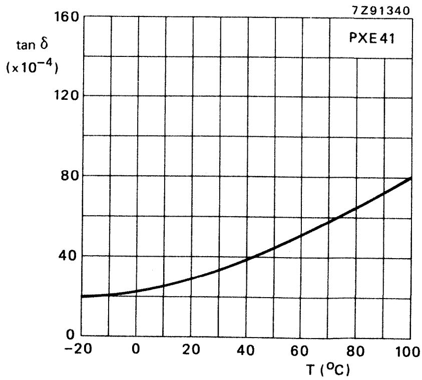


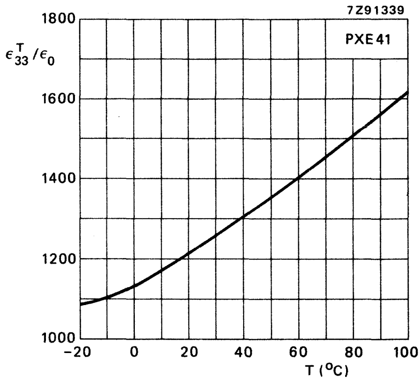


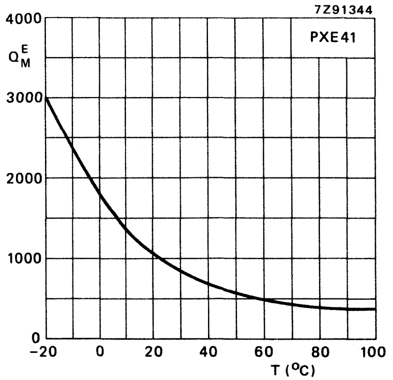






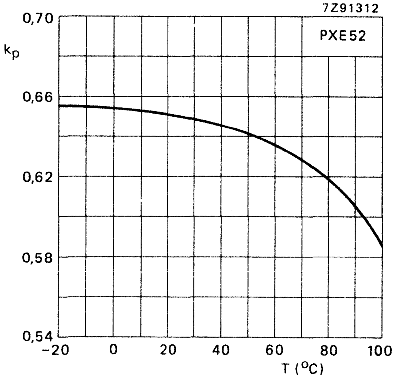


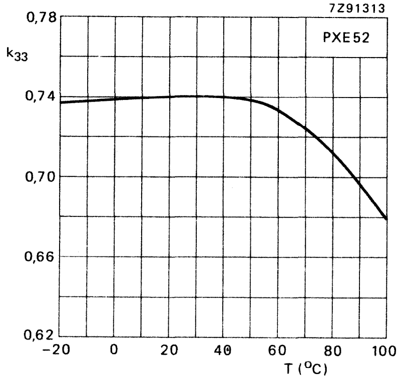

7Z91339
PXE41
$\epsilon_{33}^{T}/\epsilon_0$
1800
1600
1400
1200
1000
−20
0
20
40
60
80
100
T (°C)

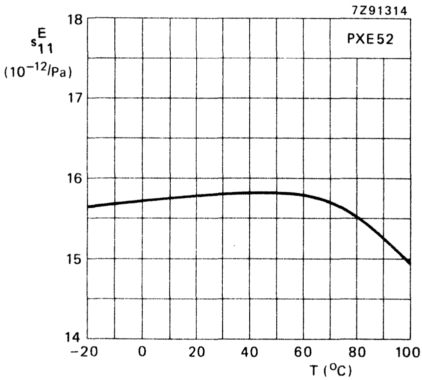

7Z91344
PXE41
Q_M^E
4000
3000
2000
1000
0
−20
0
20
40
60
80
100
T (°C)

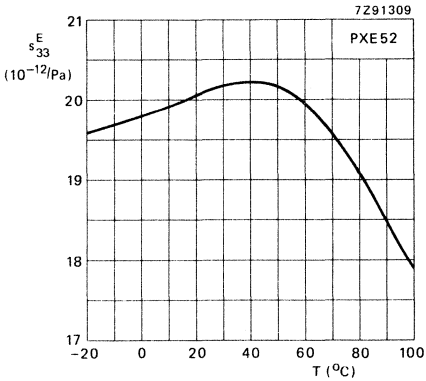
TEMPERATURE EFFECTS

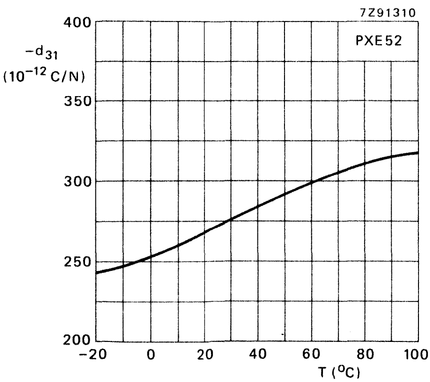
PXE 52

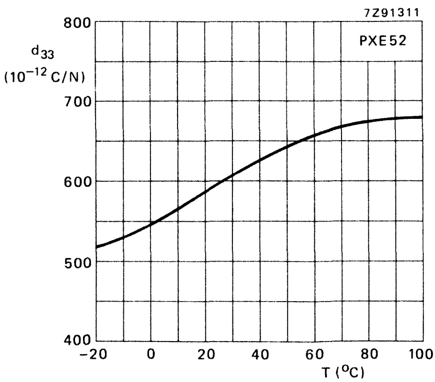


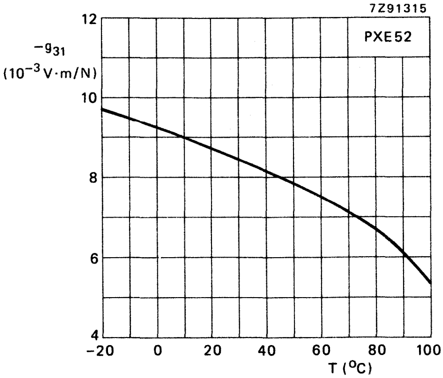


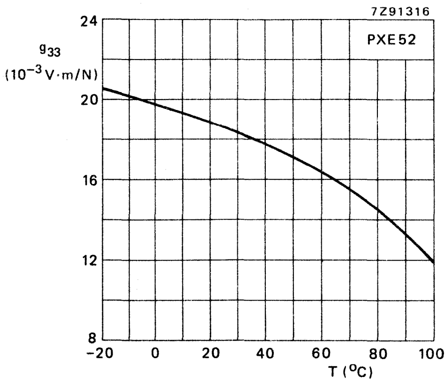


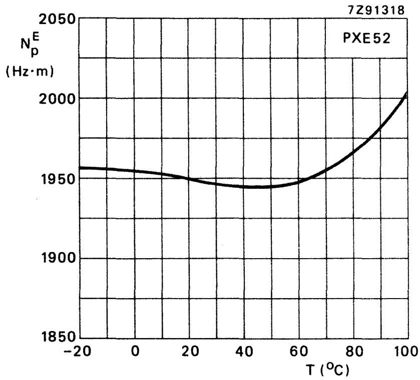


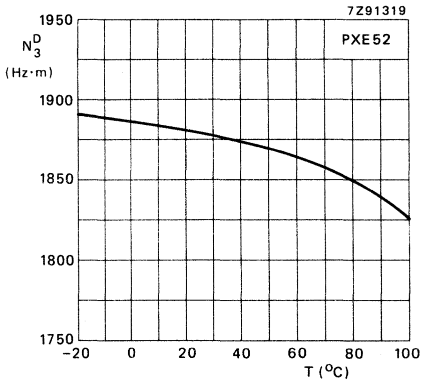


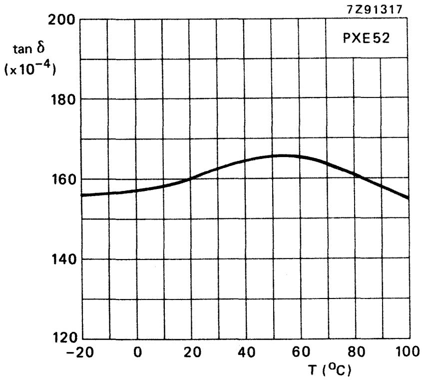


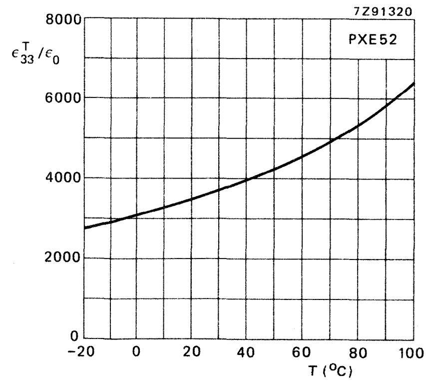

7Z91315
PXE52
$-g_{31}$
$(10^{-3}$ V·m/N)
12
10
8
6
4
−20
0
20
40
60
80
100
T (°C)


7Z91316
PXE52
g_{33}
$(10^{-3}$ V·m/N)
24
20
16
12
8
−20
0
20
40
60
80
100
T (°C)


7Z91318
PXE52
N_p^E
(Hz·m)
2050
2000
1950
1900
1850
−20
0
20
40
60
80
100
T (°C)


7Z91319
PXE52
N_3^D
(Hz·m)
1950
1900
1850
1800
1750
−20
0
20
40
60
80
100
T (°C)

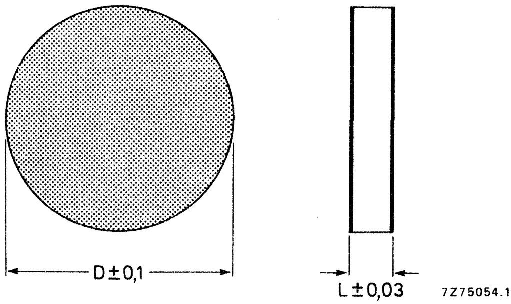

7Z91317
PXE52
tan δ
$(\times 10^{-4})$
200
180
160
140
120
−20
0
20
40
60
80
100
T (°C)


7Z91320
PXE52
$\epsilon_{33}^T/\epsilon_0$
8000
6000
4000
2000
0
−20
0
20
40
60
80
100
T (°C)

DISCS AND PLATES

DISCS with nickel plated electrodes

PXE discs can be used in a great number of applications. Electrical contact may be made by soldering, bonding or clamping wires to the electrodes. The grade is PXE 5, but other grades and sizes may be asked for. A non-metallized edge of 0,5 mm is allowed for 10-16-20 and 25 mm dia.

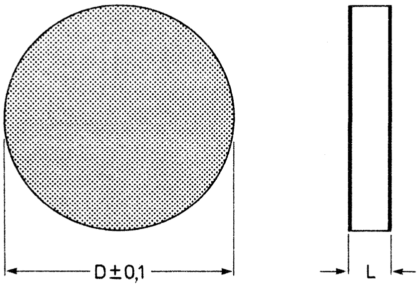


Material: PXE 5

D mm	L mm	catalogue number
5,0	0,3	4322 020 17500
5,0	0,5	17510
5,0	1,0	17520
5,0	2,0	17530
10,0	0,2	4322 020 17540
10,0	0,5	17550
10,0	1,0	17560
10,0	2,0	17570
10,0	3,0	17580
10,0	5,0	17590
16,0	0,2	4322 020 17600
16,0	0,5	17610
16,0	1,0	17620
16,0	2,0	17630
16,0	3,0	17640
20,0	0,2	4322 020 17650
20,0	0,5	17660
20 0	1,0	17670
20,0	2,0	17680
25,0	0,2	4322 020 17690
25,0	0,5	17700
25,0	1,0	17710
25,0	2,0	17720

DISCS with silver plated electrodes*

A non-metallized edge of 0,5 mm is allowed for 10-16 and 25,4 mm dia.



7Z90768

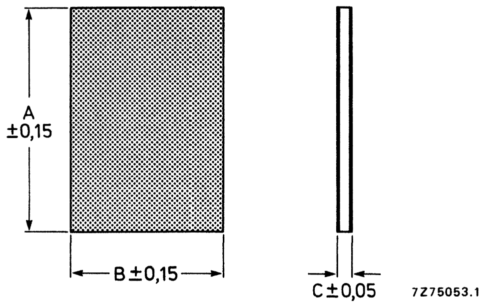
Material: PXE 5

D mm	L mm	catalogue number
5,0	0,3 ± 0,05	4322 020 05270
5,0	0,5 ± 0,05	05280
5,0	1,0 ± 0,1	05300
5,0	2,0 ± 0,1	05310
10,0	0,5 ± 0,05	4322 020 05340
10,0	1,0 ± 0,1	02330
10,0	2,0 ± 0,1	05350
10,0	3,0 ± 0,1	05360
10,0	5,0 ± 0,1	05370
16,0	0,5 ± 0,05	4322 020 05410
16,0	1,1 ± 0,1	02250
16,0	2,0 ± 0,1	05420
16,0	3,0 ± 0,1	02300
25,4	0,5 ± 0,05	4322 020 05430
25,4	1,0 ± 0,1	05440
25,4	2,0 ± 0,1	05450

* Nickel plated is preferred for new designs. See previous page.

PLATES with nickel plated electrode

Square and rectangular plates. Electrical contact may be made by soldering, bonding or clamping wires to the electrodes. The material grade is PXE 5, but other grades and sizes with thickness of 0,25 to 1,0 mm may be asked for.

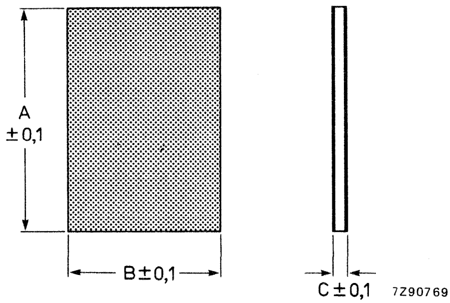


Material: PXE 5 $k_{31} \geqslant 0{,}30$

A mm	B mm	C mm	catalogue number
4	4	0,3	4322 020 13500
6	4	0,3	13510
8	4	0,3	13520
10	4	0,3	13530
12	4	0,3	13540
6	6	0,3	4322 020 13550
8	6	0,3	13560
10	6	0,3	13570
12	6	0,3	13580
8	8	0,3	4322 020 13590
10	8	0,3	13600
12	8	0,3	13610
10	10	0,3	4322 020 13620
12	10	0,3	13630
12	12	0,3	4322 020 13640

PLATES with silver plated electrodes*

The positive pole is marked.



Material: PXE 5 $k_{31} \geqslant 0{,}30$

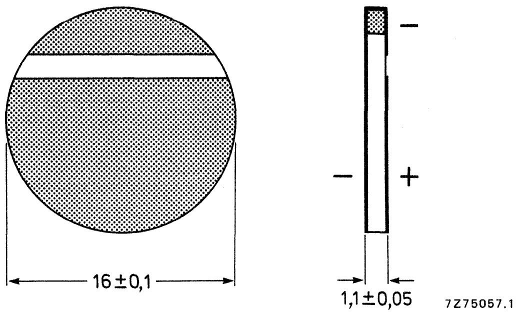
A mm	B mm	C mm	catalogue number
6	4	0,5	4322 020 07150
12	6	0,5	07050
12	6	1,0	07060
16	12	1,0	02310

* Nickel plated is preferred for new designs. See previous page.

DISCS AND PLATES for one side connection

These devices have provision for connecting both electrodes from one side by means of a wrap-round electrode as shown below; they are therefore particularly suitable for bonding to flat substrates where electrical connection to both sides is difficult. The electrodes are silver.

DISC

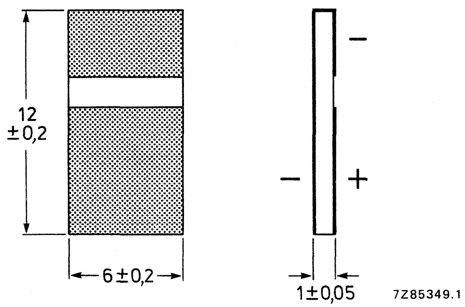


Material: PXE 5

Effective coupling factor k_{eff}: ⩾ 0,30

Catalogue number: 4322 020 02270

PLATE



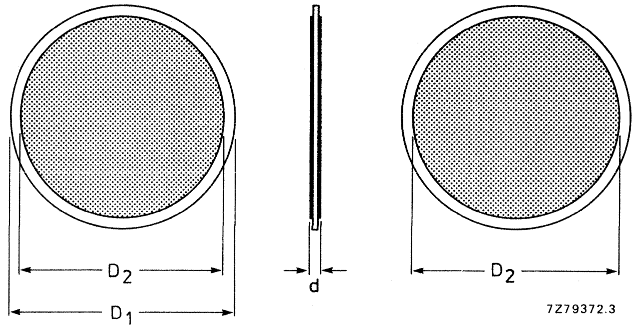
Material: PXE 5

Catalogue number: 8222 293 27130

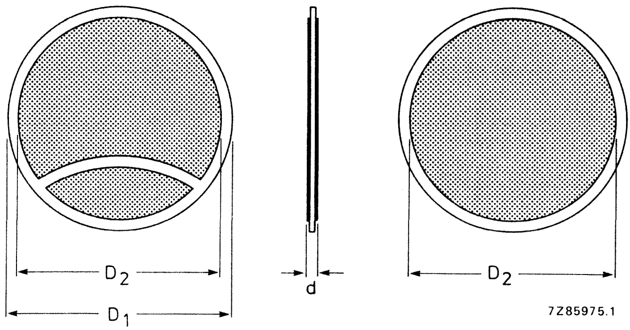
DISCS for audio applications, acoustic elements

For use in devices such as clocks and watches, smoke alarm devices, audio alarms, telephone/microphone, small loudspeakers and tweeters.

Available in 2-electrode- or 3-electrode version.
Electrodes are nickel, solderable.



Two electrode configuration.



Three electrode configuration.

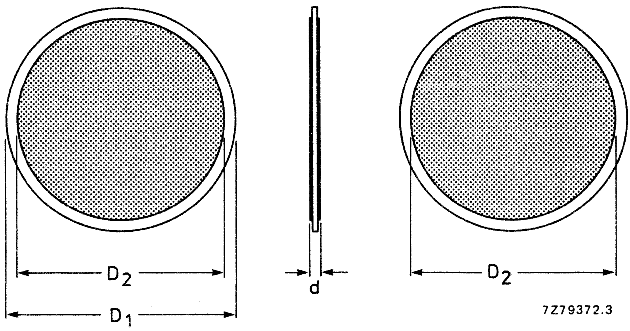
Material grade: PXE 52

D_1 mm	D_2 mm	d mm	2-electrodes catalogue no.	3-electrodes catalogue no.
10	9	0,11	4322 020 17730	
16	15	0,15	17740	4322 020 17770
20	19	0,15	17750	17780
25	24	0,15	17760	17790

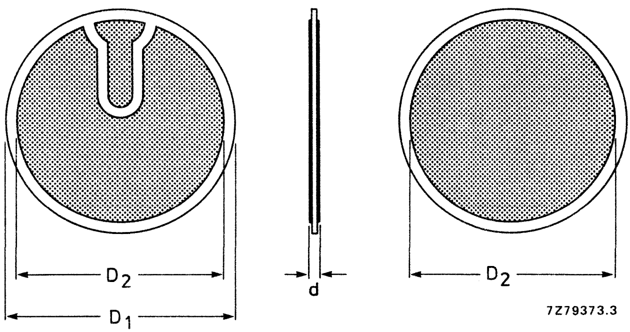
DISCS with silver plated electrodes. Not for new designs.

Available in 2-electrode or 3-electrode version.

Electrodes are silver.*



Two electrode configuration.



Three electrode configuration.

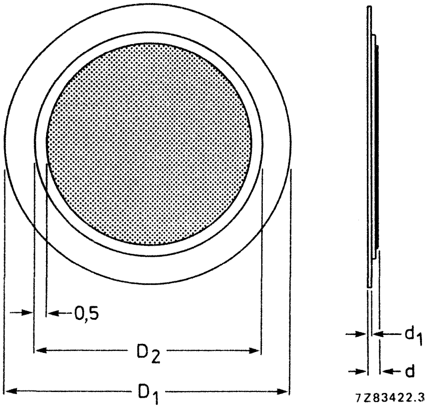
Material grade: PXE 52

D_1 mm	D_2 mm	d mm	2-electrodes catalogue no.	3-electrodes catalogue no.
10	9	0,2	4322 020 08450	–
16	15	0,2	08430	4322 020 05970
20	19	0,2	8222 293 24050	8222 293 24060
25	24	0,2	8222 293 24030	8222 293 24040

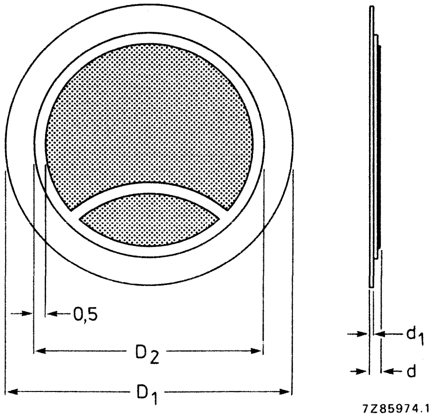
* See data on preferred types with nickel electrodes.

DISCS glued on nickel plated membrane for buzzers; acoustic elements

Available in 2-electrode or 3-electrode version
Electrodes are **nickel**, solderable.



Two electrode configuration.



Three electrode configuration.

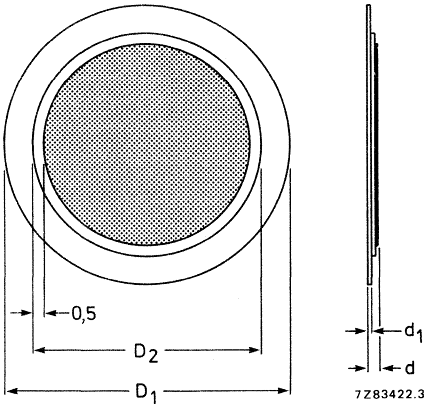
Material: PXE 52

D_1 mm	D_2 mm	d1 mm	d mm	2 electrodes catalogue no.	3 electrodes catalogue no.
12,5	10	0,1	0,3	4322 020 16320	–
20	16	0,15	0,4	16330	4322 020 16390
27	20	0,15	0,4	16340	16400
35	25	0,15	0,4	16350	16410
43	25	0,15	0,4	16360	–
46	25	0,15	0,4	16370	–
50	25	0,15	0,4	16380	–

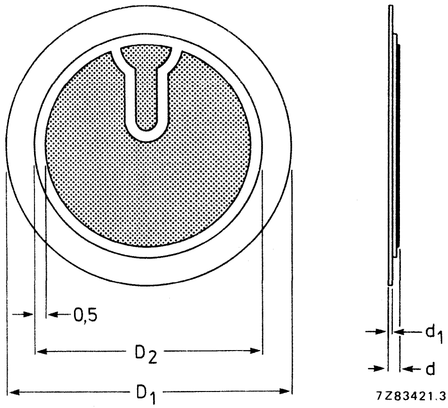
DISCS glued on nickel plated membrane for buzzers Not for new designs.

Available in 2-electrode or 3-electrode version.

Electrodes are silver.*



Two electrode configuration.



Three electrode configuration.

Material: PXE 52

D_1 mm	D_2 mm	d1 mm	d mm	2 electrodes catalogue no.	3 electrodes catalogue no.
12,5	10	0,1	0,4	4322 020 08860	–
20	16	0,2	0,5	08820	4322 020 08870
27	20	0,2	0,5	08840	08880
35	25	0,2	0,5	08850	08890

* See data on preferred types with nickel electrodes.

TWEETER MEMBRANE

For high frequency tweeter loudspeakers.

Available with or without leads. The electrodes are either silver or nickel plated (preferred). The positive pole is marked.

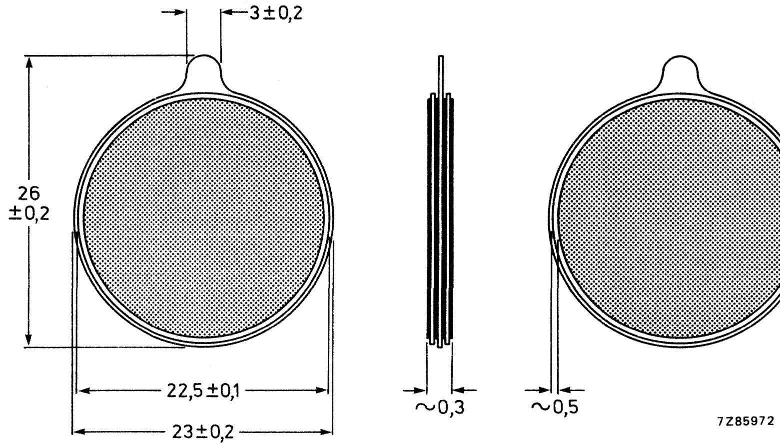


Fig. 1 Without leads.

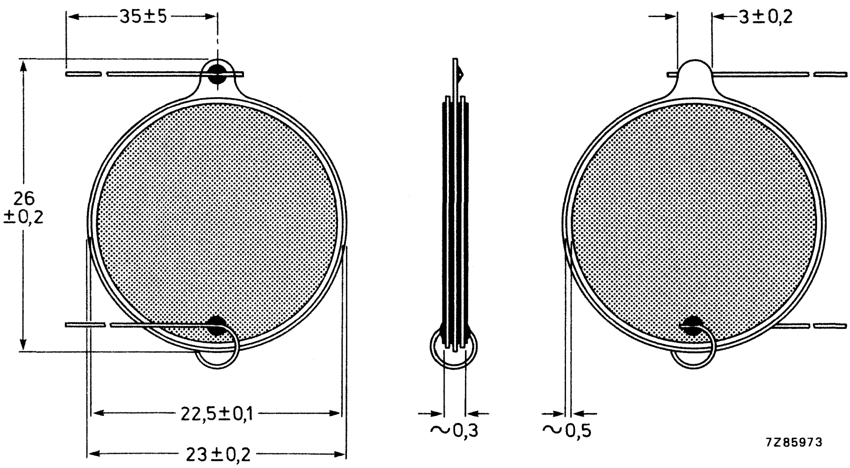


Fig. 2 With leads.

Material: PXE 52

	without leads catalogue no.	with leads catalogue no.
silver electrodes	8222 293 26790	8222 293 28880
nickel electrodes	8222 293 30270	8222 293 30280

ACTUATORS

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

Actuators

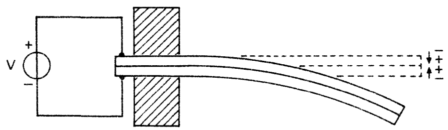
- Low Power Actuators
  - displacement: some mm
  - force : max. 1N
  - Construction
    - Flexure Elements
      - Series Bimorphs
      - Parallel Bimorphs
- High Power Actuators
  - displacement: max. 0,5 mm
  - force : 1 N up to 5000 N
  - Construction
    - Flexure Elements
      - Series Bimorphs
      - Parallel Bimorphs
    - Stacked Elements

PXE FLEXURE ELEMENTS: BIMORPH

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

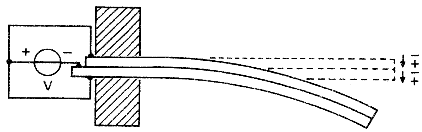
A much more compliant structure operating in the 31 mode is the flexure element, the simplest form of which is the bilaminar cantilever or *bimorph*. This consists of two thin PXE strips bonded together. Bimorphs are usually mounted as a cantilever and usually operate in the 31 mode (see Figs 1 and 2).

A *series bimorph* is one whose PXE strips are connected to the voltage source in series (Fig. 1), and a *parallel bimorph* is one whose strips are individually connected to the voltage source (Fig. 2).



7Z91280

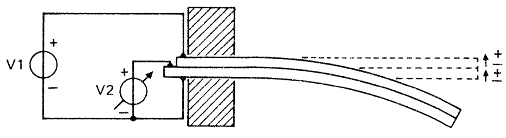
Fig. 1 Series bimorph.



7Z91281

Fig. 2 Parallel bimorph.

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. 2, but if it is connected as shown in Fig. 3, both strips will be driven in the polarization direction, thereby avoiding drift in characteristics caused by depolarization.

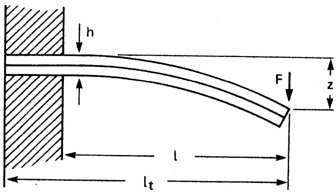


$V2 \leqslant V1$

7Z91282

Fig. 3.

PRACTICAL DESIGN DATA



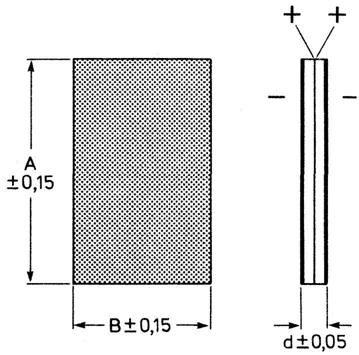
7Z91279

l_t = total length
F = force on tip
W = width
l = free length
h = total thickness
z = deflection of tip
V = applied voltage, field strength 250 to 500 V/mm

	parallel	series
deflection (m) (active)	$9 \cdot 10^{-10} \frac{l^2}{h^2} V$	$4{,}5 \cdot 10^{-10} \frac{l^2}{h^2} V$
bending (N/m) (passive)	$7 \cdot 10^{-11} \frac{l^3}{Wh^3} F$	$7 \cdot 10^{-11} \frac{l^3}{W.h^3} F$
resonance frequency (Hz)	$400 \frac{h}{l^2}$	$400 \frac{h}{l^2}$
charge output (C)	$2 \cdot 10^{-3}\ l^2\ F$	$1 \cdot 10^{-3}\ l^2\ F$
capacitance (F)	$8 \cdot 10^{-8} \frac{l_t W}{h}$	$2 \cdot 10^{-8} \frac{l_t W}{h}$
voltage output (V)	$2{,}5 \cdot 10^{4} \frac{l^2 h}{l_t W} F$	$5 \cdot 10^{4} \frac{l^2 h}{l_t W} F$

SERIES BIMORPH PLATES

A range of square and rectangular plates in grade PXE 5 for use in record players, accelerometers, detection systems in machinery, medical equipment and air transducers. The electrodes are nickel plated and are solderable.



7Z85971

Material: PXE 5

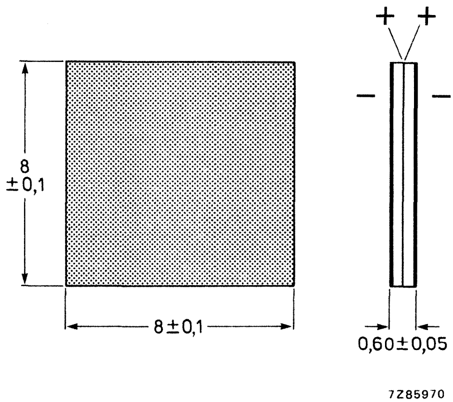
A mm	B mm	d mm	catalogue number
4	4	0,6	4322 020 04570
6	4	0,6	04580
8	4	0,6	04590
10	4	0,6	04600
12	4	0,6	04610
6	6	0,6	04620
8	6	0,6	04630
10	6	0,6	04640
12	6	0,6	04650
8	8	0,6	04660
10	8	0,6	04670
12	8	0,6	04680
10	10	0,6	04690
12	10	0,6	04700
12	12	0,6	04710
12,7	1,6	0,6	08250
15,5	1,6	0,6	08240
70	1,6	0,6	08230

Other sizes on request.

SERIES BIMORPH PLATE

for ultrasonic air transducers, operating at resonant frequency

A bimorph plate used to generate or detect ultrasound in air, e.g. counting and monitoring (for example on a production line), level control of liquids and powders, movement detection, remote control of machines and equipment (for example TV receivers), and intruder alarms. The electrodes are silver plated*. Not for new designs.

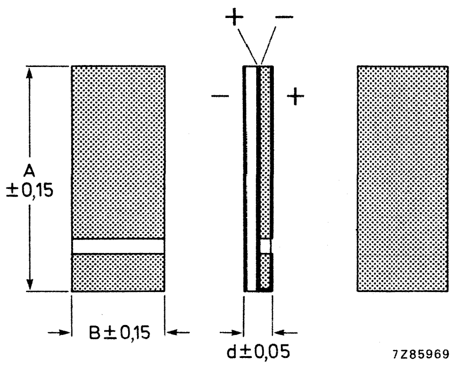


Material		PXE 5
Resonant frequency	f_s	34,5 ± 3,0 kHz
Capacitance at 1 kHz		1450 ± 290 pF
Catalogue number		4322 020 08120

* Nickel plating is preferred, see previous page.

PARALLEL BIMORPH PLATES

A range of rectangular parallel bimorph plates in grade PXE 5 of which the inner electrode is executed as a wrap-round. The electrodes are nickel plated and are solderable.



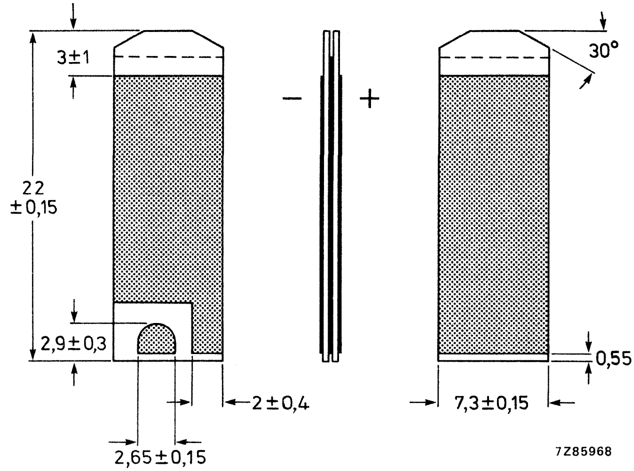
Material: PXE 5

A mm	B mm	d mm	catalogue number
15	6	0,6	4322 020 14530
20	6	0,6	14540
25	6	0,6	14550
30	6	0,6	14560
35	6	0,6	14570
15	12	0,6	14580
20	12	0,6	14590
25	12	0,6	14600
30	12	0,6	14610
35	12	0,6	14620

Other sizes on request.

PARALLEL BIMORPH PLATE

This plate is used for dynamic track sensing in VCR2000 equipment. It consists of two polarized plates bonded together to a parallel bimorph plate. The electrodes are nickel plated and can be soldered.

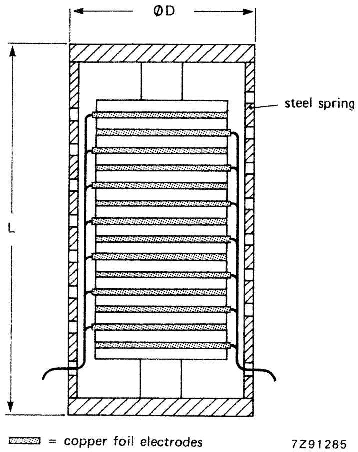


Material	PXE 5
Catalogue number	4322 020 07590
Resonant frequency	900 Hz $< f_s <$ 1300 Hz
Deflection	measured at 25 to 100 Hz with 300 V (peak to peak), free length 15,2 mm, 215 to 280 μm (peak to peak)

HIGH-POWER ACTUATOR

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 about 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 around 200 μs.



catalogue number	4322 020 19050	4322 020 19060	4322 020 19070	
Dimensions D x L	15 x 50	20 x 75	30 x 100	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
Max. applied force	2000	3000	5000	N

PIEZOELECTRIC CERAMICS FOR ULTRASONIC TRANSDUCERS

INTRODUCTION

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 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 which 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 kHz to 60 kHz and causes the tank wall to vibrate in complex flexure modes, radiating ultrasound in to 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 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 kHz 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.

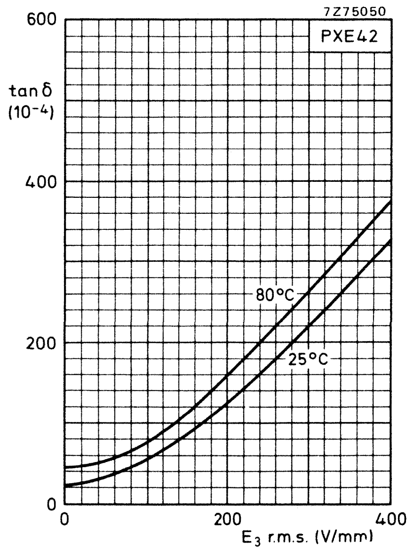
DYNAMIC BEHAVIOUR OF THE TRANSDUCER

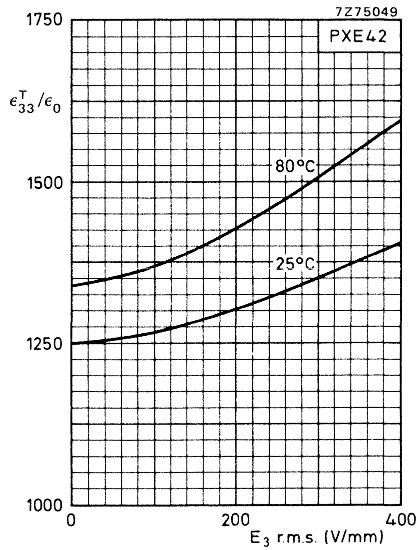
High intensity transducers are normally driven at resonance, and the equivalent circuit is as in Fig. 3*. For maximum efficiency, the transducer should be tuned electrically by means of an inductance given by $L = 1/(4\pi^2 f^2 C_O)$. The impedance of the transducer then appears as purely ohmic.

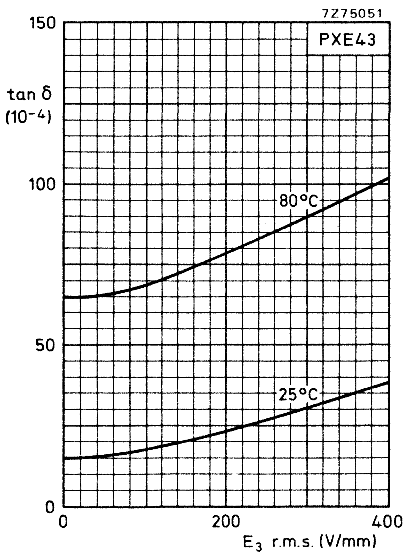
* See Intruduction.

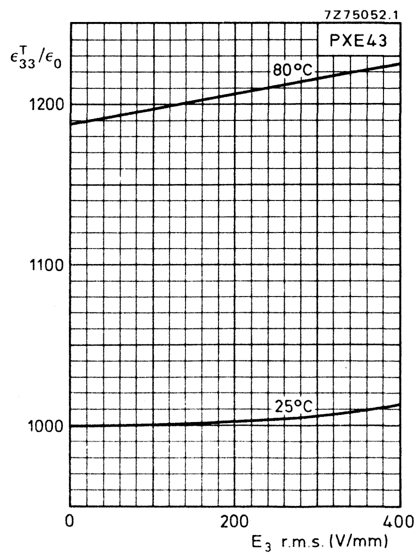
LARGE-SIGNAL PROPERTIES OF PXE 42 AND PXE 43

Behaviour of tan δ and relative permittivity $\epsilon_{33}^{T}/\epsilon_0$ under large driving fields.

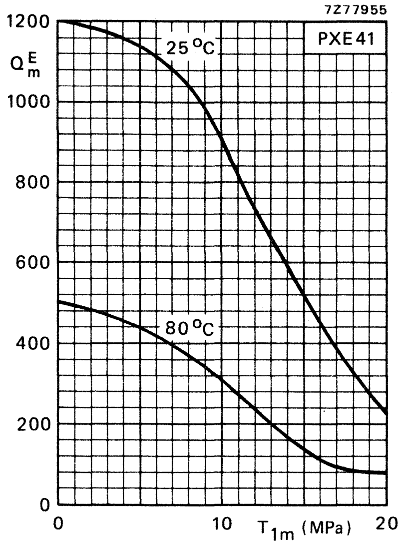


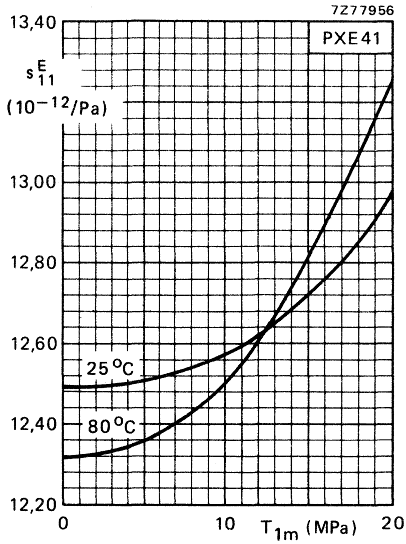


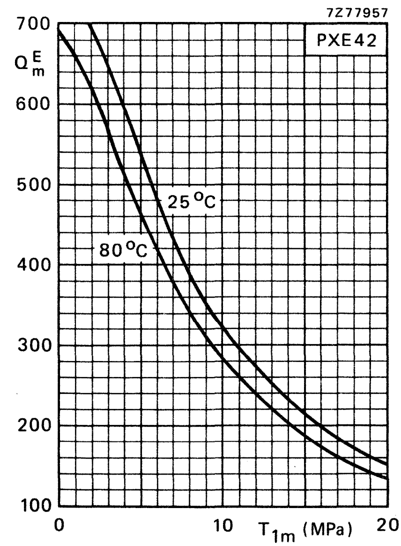


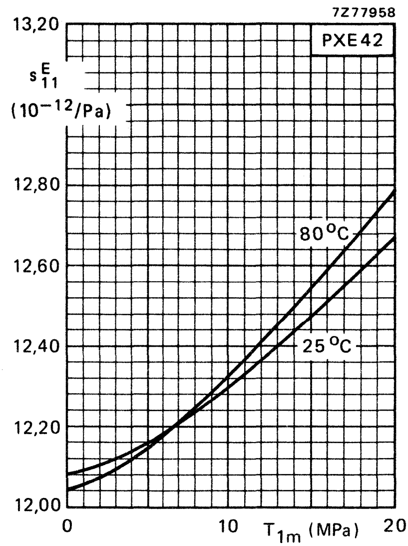


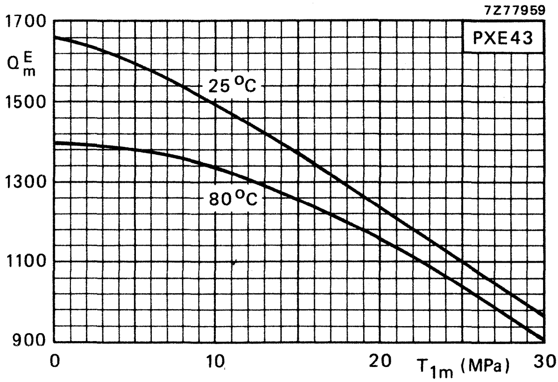
Variation of mechanical quality factor Q_m^E and elastic compliance s_{11}^E with dynamic stress in PXE 41, PXE 42, PXE 43.

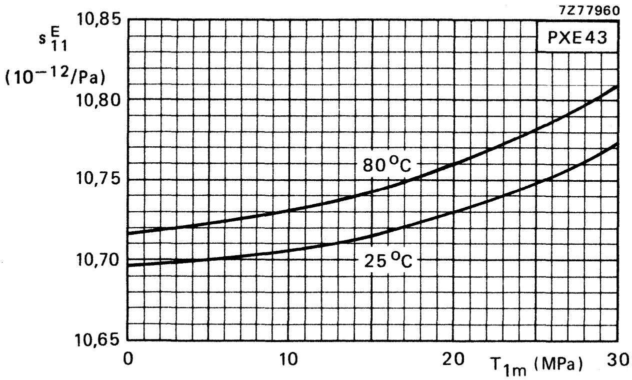









7Z77959
PXE43
1700
Q_m^E
1500
1300
1100
900
25 °C
80 °C
0
10
20
30
T_{1m} (MPa)


7Z77960
PXE43
s_{11}^E
(10^{-12}/Pa)
10,85
10,80
10,75
10,70
10,65
80 °C
25 °C
0
10
20
30
T_{1m} (MPa)

PIEZOELECTRIC RINGS
for ultrasonic applications

The electrodes of the rings are silver plated. The electrode which has been connected to the positive terminal of the polarizing apparatus is identified. The direction of polarization is axial.

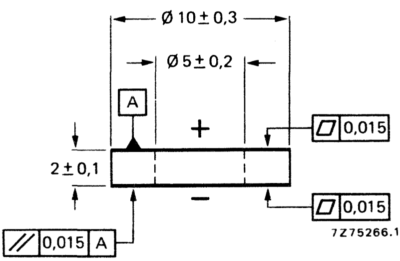
TECHNICAL DATA

Catalogue number	4322 020 06060	4322 020 06130	4322 020 06170
Dimensions in mm	ϕ 10 x ϕ 5 x 2	ϕ 20 x ϕ 6 x 5	ϕ 20 x ϕ 6 x 5
Material	PXE 41	PXE 42	PXE 41
f_p/f_s	$\geqslant$ 1,05	$\geqslant$ 1,05	$\geqslant$ 1,05
Nominal capacitance (pF)	320	650	650
Tan δ max.	4,0	4,0	4,0 x 10^{-3}

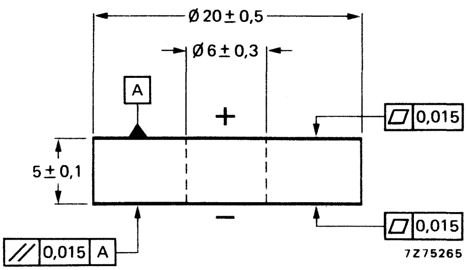
APPLICATIONS

For use in a wide range of applications, e.g.:
- low-power ultrasonic microbonding in semiconductor processes;
- ultrasonic drilling of small holes;
- ultrasonic dental descalers;
- small ultrasonic cleaning devices;
- underwater acoustics.

MECHANICAL DATA



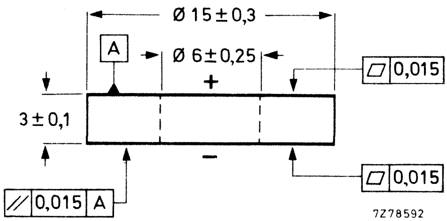
Type 4322 020 06060



Types 4322 020 06130 and 4322 020 06170

PIEZOELECTRIC RING
for ultrasonic atomisers

The electrodes of the ring are silver plated. The electrode which has been connected to the positive terminal of the polarizing apparatus, is identified. The direction of polarization is axial.



Material	PXE 42
f_p/f_s	⩾ 1,06
Nominal capacitance	550 pF
Tan δ max.	$4{,}0 \times 10^{-3}$
Catalogue number	8222 293 24720

PIEZOELECTRIC DISCS

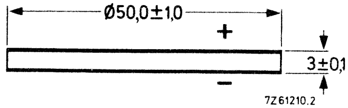
for ultrasonic cleaning

The electrodes of the discs are silver plated. The electrode which has been connected to the positive terminal of the polarizing apparatus, is identified. The direction of polarization is axial.

Material: PXE 41

Nominal capacitance: 7200 pF

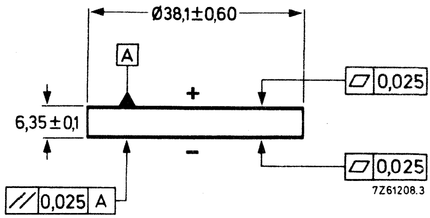
Catalogue number: 4322 020 05590



Material: PXE 42

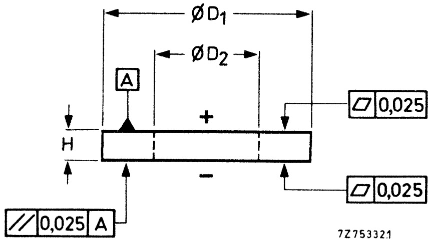
Nominal capacitance: 2000 pF

Catalogue number: 4322 020 05660



PIEZOELECTRIC RINGS
for ultrasonic cleaning

The electrodes of the rings are silver plated. The electrode which has been connected to the positive terminal of the polarizing apparatus, is identified. The direction of polarization is axial.

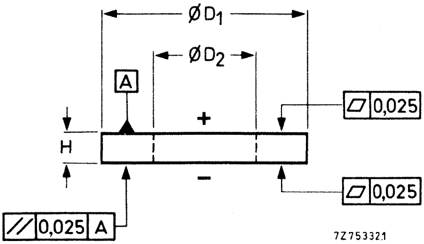


Material: PXE 42

D_1 mm	D_2 mm	H mm	nom. capacitance pF	catalogue number
38,1 ± 0,6	12,7 ± 0,35	4 ± 0,1	2800	4322 020 06090
38,1 ± 0,6	12,7 ± 0,35	6,35 ± 0,1	1800	4322 020 06040
38,1 ± 0,6	19,1 ± 0,5	6,35 ± 0,1	1500	4322 020 06070
50 ± 1	20 ± 0,5	6 ± 0,1	3000	4322 020 06050
50,5 ± 1	17,0 ± 0,5	6,35 ± 0,1	3100	4322 020 06120

PIEZOELECTRIC RINGS
for ultrasonic welding

The electrodes of the rings are silver plated. The electrode which has been connected to the positive terminal of the polarizing apparatus, is identified. The direction of polarization is axial.



Material: PXE 43

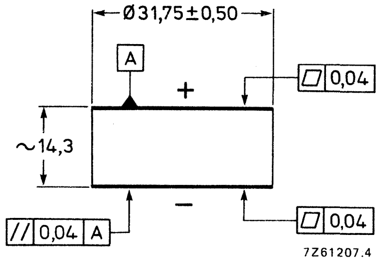
D_1 mm	D_2 mm	H mm	nom. capacitance pF	catalogue number
20 ± 0,5	6 ± 0,3	5 ± 0,1	500	4322 020 06290
25 ± 0,6	10 ± 0,3	5 ± 0,1	725	4322 020 06280
38,1 ± 0,6	12,7 ± 0,35	6,35 ± 0,1	1400	4322 020 06270
38,1 ± 0,6	19 ± 0,5	5 ± 0,1	1500	4322 020 06160
50 ± 1	20 ± 0,5	5 ± 0,1	2900	4322 020 06150
50 ± 1	20 ± 0,5	6 ± 0,1	2400	4322 020 06140

PIEZOELECTRIC DISCS

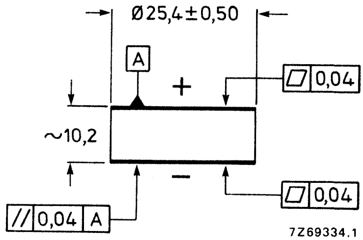
for echo sounding probes

The electrodes of the discs are silver plated. The electrode that has been connected to the positive terminal of the polarizing apparatus, is identified. The direction of polarization is axial.

Material:	PXE 41
Resonant frequency:	151 ± 5 kHz (thickness mode)
Thickness:	approx. 14,3 mm (adapted to resonant frequency)
Nominal capacitance:	approx. 620 pF
Catalogue number:	4322 020 05240

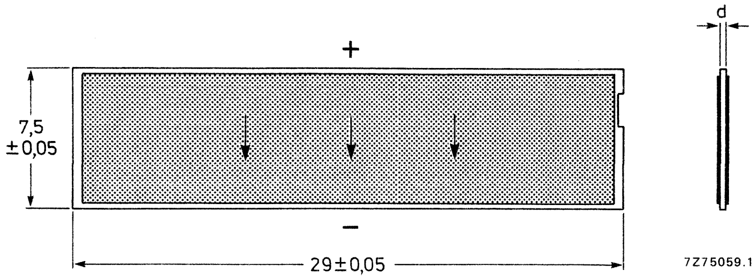


Material:	PXE 41
Resonant frequency:	200 ± 10 kHz (thickness mode)
Thickness:	approx. 10,2 mm (adapted to resonant frequency)
Nominal capacitance:	approx. 520 pF
Catalogue number:	4322 020 05750



TRANSDUCER FOR DELAY LINES

These products are used in modern acoustic delay systems with an electro-mechanical transducer which converts electric signals to acoustic signals and back again to electric signals, after having travelled through an acoustic delay medium. Example: colour television receivers.



Material:	PXE 71
Resonant frequency:	4,1 ± 0,1 MHz
Thickness (d):	approx. 0,24 mm (adapted to resonant frequency)
Nominal capacitance:	13 300 pF
Catalogue number:	3322 027 09001

NOTES

NOTES

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