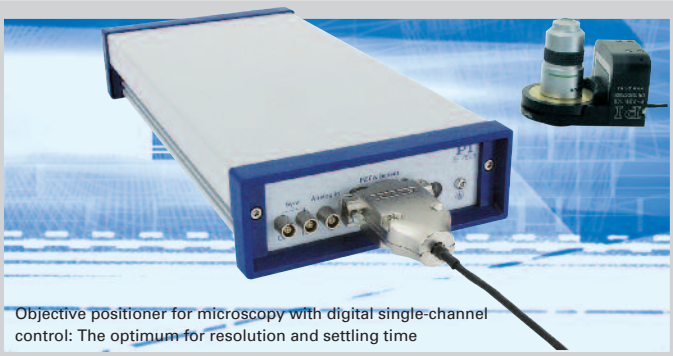
Digital Control

Best Performance for Positioning Systems

Contents

Digital Control

Digital Processes Improve Performance



Objective positioner for microscopy with digital single-channel control: The optimum for resolution and settling time

Digital technology opens up new opportunities for improving performance in control engineering which did not exist with conventional analog technology.

A significant advantage of PI's digital controllers is that all motion parameters can be specifically influenced by calculating algorithms.

These advantages lie mainly in the improved precision and dynamic properties, and also the ease of operation of PI's positioning systems and drive solutions.

High-Resolution Signal Conversion

The most important requirement here is that the signal conversion from analog input signals to digital data for the subsequent processing is done quickly and with high resolution. Information which is lost at conversion is lost forever. The same applies to the generation of the analog control signal: The best algorithms are useless if the analog control signal cannot be generated in high resolution. PI therefore uses the latest generation of A/D and D/A converters with a minimum 20-bit resolution. Analog signals are thus resolved into more than one million data points.

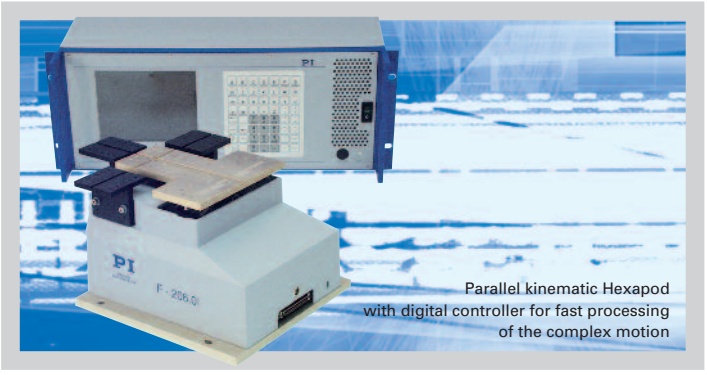
Fast Data Processing

The incoming volume of data needs to be processed rapidly in order to compete with the conventional analog controllers in terms of "real time". This requires fast processors. PI relies on modern DSPs and powerful PC solutions, depending on the task the controller has to fulfill.

A control cycle is thus completed, for example, in 0.02 milliseconds – this corresponds to a servo rate of 50 kHz. Updated sensor data and control signals have therefore also to be provided.

Digital Processes Improve Performance

The performance of a positioning system is no longer decided by its mechanical properties alone. In the case of dynamic applications, for example, it is naturally also important that the system is as stiff as possible and the moving mass very small, the sensor bandwidth broad and the amplifier flank steep. There will nevertheless be phase shifts between the control signal – the target motion – and the actual motion. Linearization algorithms minimize the difference between the target and the actual value and allow faster settling and also the adjustment of the control signal.



Parallel kinematic Hexapod with digital controller for fast processing of the complex motion

Digital Data Processing

Classical nanopositioning technology employs the following algorithms in digital controllers to improve the system performance:

Linearization of the Electronics:

All digital PI controllers for nanopositioning behave in a similar way. This allows any piezo devices which are tuned to digital control to also be operated by different controllers without any loss of performance. The tuning data required are stored on an ID-Chip in the stage and retrieved by the controller at power up.

Linearization of the Mechanics:

The linearity of regulated systems as a whole is a measure of its positional accuracy. Piezo actuators as such have a high degree of nonlinearity – up to 15% of the travel – and this must be compensated by the control in order for the system to reach the position as accurately as possible. With digital controllers, the nonlinearity of the motion is reduced using calculations with higher order polynomials to values below 0.001% – which corresponds to an accuracy of better than one nanometer for a travel range of 100 µm.

Controller and Controlling Methods:

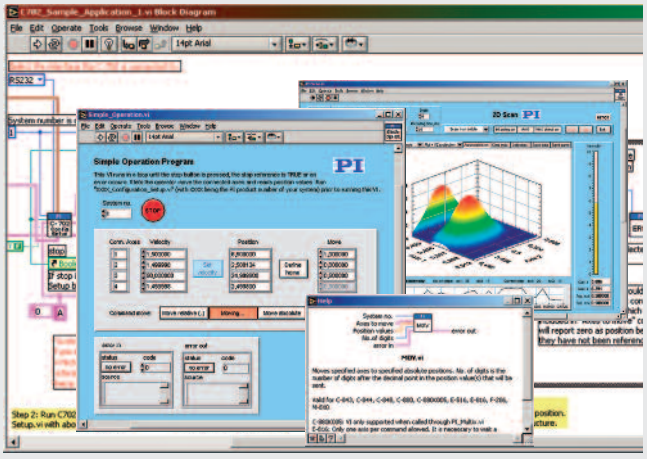
The task of the controller is to compensate differences between target and actual position. This is conventionally done with PID controllers. Depending on the application, other control concepts in combination with linearizing algorithms can bring about better results, however. PI thus offers model-based state controllers (Advanced Piezo Control) as an optional extra.

Dynamic Linearization:

Digital Dynamic Linearization (DDL) reduces the deviation of periodic trajectories during the motion even further. This is relevant for scanning applications, where the task is to identify a certain position and take it up again with precision, or for applications where the trajectory must be maintained for processing steps.

Digital Control

Simplified Operation and Advanced Functionality



Quick access to the full functionality

Operation via Software

The complete digitalization of all operational steps makes the process parameters easily accessible via software. PI software additionally provides diagnostic tools and tuning support, such as the graphic display of step responses for parameter optimization.

Operation via Digital Interfaces

Fast USB or TCP/IP interfaces, as well as RS-232, are the standard interfaces supported by modern digital controllers. Furthermore, PI also provides real-time capable interfaces such as a 32-bit parallel input / output interface (PIO). Customized serial interfaces are also possible to provide a link to the application environment.

Simplified Control of Multi-Axis Systems

PI uses parallel kinematics for precise positioning in three or more axes. The actuators and drives here act simultaneously on the platform to be moved – in the case of hexapods, for example. The motion of the platform in the six directions requires that the individual axes be coordinated. This coordinate transformation enables the user to place commands in Cartesian coordinates, while the controller controls the individual drives required for this.

Additional Functions of the Digital Controllers*

Computing power and memory size which go hand in hand with digital controllers allow useful additional functions to be implemented.

Coordinate transformation for parallel kinematics for simple control in Cartesian coordinates.

Coordination of the walk motion for PiezoWalk® Drives; linearization of the actuator travel for Walk Drives.

Software access to all motion parameters and the graphic display of the effects.

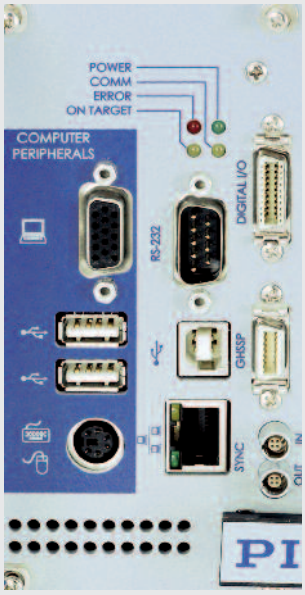
Macro memory to store and retrieve motions which can be triggered externally.

Function generator and trajectory memory for the retrieval of predefined trajectories and the generation of customized wave forms.

Data recorders record sensor and control data for subsequent processing.

The **ID Chip** permits the flexible exchange of controllers and nanopositioners without the need to retune the operational parameters.

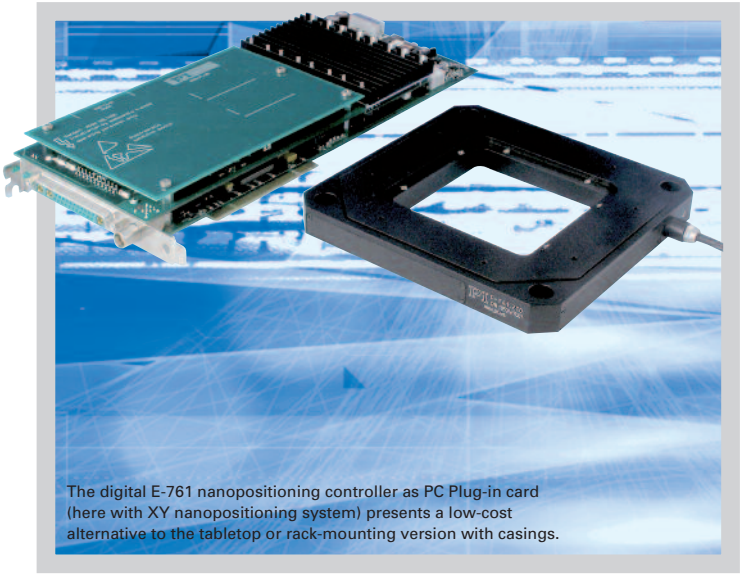
* Not all controllers have all the functions.
The individual ranges of functions are listed in the relevant datasheets.



The E-712 provides RS-232, USB and RS-232 as standard interfaces. Additionally, digital I/O lines and optional analog interfaces or a real-time PIO are available.

Digital Control

Exceeding the Pure Function…



The digital E-761 nanopositioning controller as PC Plug-in card (here with XY nanopositioning system) presents a low-cost alternative to the tabletop or rack-mounting version with casings.

Piezo, Nano, Positioning

PI offers the world's largest selection of positioning and drive systems for precise positioning in the accuracy range from one micrometer down to below one nanometer. Piezo actuators, piezo walk or ultrasonic drives as well as conventional motors and combinations of all these enable PI to provide custom-engineered positioning systems. The requirements of biotechnology, semiconductor production, optical metrology and astronomy have one thing in common here: The high degree of precision required and PI as the supplier of the solution.

Continuous Progress

As far as PI is concerned, the certification of a quality management system is a commitment to continuously improve products and processes. Suppliers are integrated into the development process in order to transfer PI's high standards to them. PI's absolute commitment to quality leads it to train its own staff in Development and Production, provide laboratories for EMC and environmental tests, and use the latest CAD and simulation tools. A commitment which those working in the field of nanotechnology cannot do without.

As Flexible as the Drive: The Control

Fast settling or slow speed with high constancy, high positional stability, positional resolution and dynamics – different applications require a high degree of control flexibility. PI therefore offers a broad spectrum of electronics from very versatile controllers to highly specialized ones: As an OEM board for integration, a plug-and-play desktop unit or with a modular construction.

Piezo Amplifier in cost-efficient and compact OEM Design

Service

The **scope of supply** of a PI system consisting of controller and stage includes everything required for its operation.

- Any necessary external power supplies
- All power, communication and system cables
- The comprehensive operating manual in printed form
- Software CD with comprehensive setup function

Firmware and software updates are available free of charge via the Internet, as are the operating manuals. You will receive access to the PI download portal when you purchase the controller. Firmware updates can easily be carried out via the standard controller interfaces.

PI offers comprehensive **software support**. PI software is included in the scope of supply and serves to start up the system, and also to analyze and optimize the system's behavior. DLLs, LabView drivers or the support of MatLab facilitate the programming.

It goes without saying that the PI software is compatible with the latest Microsoft operating systems and can also be operated under LINUX.

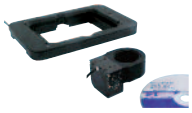
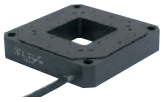
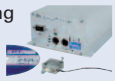
When developing the instruments, top priority is given to the use of state of the art components. This ensures a **long availability and replaceability** of the systems even beyond the product lifecycle.

Customized product development and adaptations are an important part of our technical progress. We offer you:

- The complete range of our product spectrum from electronic components and complete devices as an OEM circuit board to the modular system in a case.
- Small batch production and mass production.
- Product development according to special product standards (country or market-specific standards such as the Medical Devices Act) and the corresponding certification.
- Adaptation of the systems to special environmental conditions (vacuum, space, clean room)
- Copy-exactly agreements

Digital Control

Product Overview: As flexible as PI drives

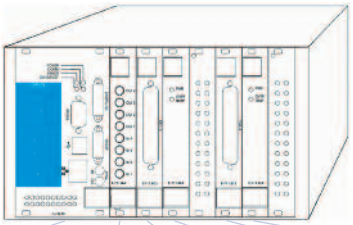
	Drives	Hardware platform	Axis	Power/channel	Interfaces	Software platform
	Nanopositioning systems with Single-Axis	 E-753	1	5 W	Ethernet, RS-232, Analog	PI General Command Set
	Nanopositioning systems with up to 3 axes, low-power requirement	 E-761	3	1,7 W	PCI Plug-In Board	PI General Command Set
	Nanopositioning systems with up to 3 axes	 E-725	3	10 W	Ethernet, USB, RS-232; optional Analog, PIO	PI General Command Set
	Nanopositioning systemes with up to 6 axes	 E-712	3 / 6	8 W	Ethernet, USB, RS-232; optional Analog, PIO	PI General Command Set
	PICOCUBE® high-speed scanner	 E-712	3	up to 15 W	Ethernet, USB, RS-232; optional Analog, PIO	PI General Command Set
	NEXLINE® heavy-duty nanopositioning drive	 E-755 E-712	1	up to 10 W	RS-232 Ethernet, USB, optional Analog, PIO (only E-712)	PI General Command Set
	NEXLINE® parallel-kinematic with up to 3 axes	 E-712	3	15 W	Ethernet, USB, RS-232; optional Analog, PIO	PI General Command Set
	Positioning systems with NEXACT® Nanopositioning Drive (with Encoder Analysis)	 E-861	1	40 W	USB, RS-232	PI General Command Set
	Positioning systems with DC-servomotors and encoder analysis / PILine® ultrasonic piezo drives with encoder analysis / stepper motors	 C-863 C-867 C-663	1		USB, RS-232, networkable	PI General Command Set
	Hexapoden/ parallel kinematics with any drives	 Included	up to 6		RS-232; depending on design, Ethernet or USB	PI General Command Set

E-712 Digital Nanopositioning Controller

Modular Platform for Precision Piezo Systems and NEXLINE® Drives

E-712 digital controller for nanopositioning systems with up to 6 axes

- **Digital Controller of the Newest Generation: 600 MHz Tact Rate; up to 50 kHz Servo Update Rate; Highly Stable 20-bit D/A Converter**
- **Real-Time Operating System for Excellent Trajectory Control**
- **Modular Design for Greatest Flexibility in Meeting Custom Requirements**
- **Auto-Loading of Calibration Data from Stage ID-Chip for Interchangeability of Controller and Mechanics**
- **Versatile Interfaces: Ethernet, USB, RS-232**
- **Optional High-Bandwidth Analog Inputs and Outputs**
- **Extensive Software Support**

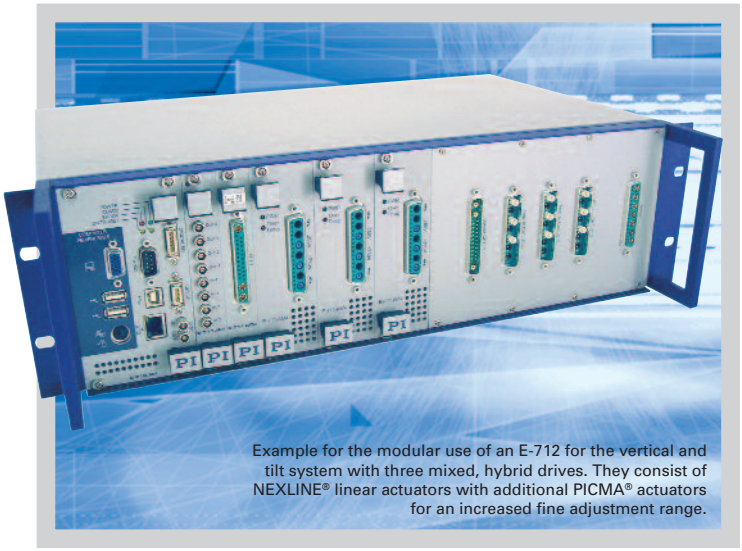


	Preconfigured system	Digital controller unit	Case unit	Interface modul	Sensor modul	Amplifier modul	Sensor modul	Amplifier modul
Nanopositioning systems with voltage requirement of up to +120 V with 3 axes and capacitive sensors	E-712.3CD	E-712.M1*	E-712.R1*	–	E-711.SC3H*	E-711.AL4P*	–	-
Nanopositioning systems with voltage requirement of up to +120 V with up to 6 axes and capacitive sensors	E-712.6CD	E-712.M1*	E-712.R1*	–	E-711.SC3H*	E-711.AL4P*	E-711.SC3H*	E-711.AL4P*
Nanopositioning systems with voltage requirement of up to +120 V with three (six) axes and capacitive sensors; 4 analog inputs and outputs for direct issuing of commands and sensor/position evaluation	E-712.3CD (E-712.6CD)	E-712.M1*	E-712.R1*	E-711.IA4	E-711.SC3H*	E-711.AL4P*	(E-711.SC3H)*	(E-711.AL4P)*
Nanopositioning systems with voltage requirement of up to +120 V with 3 (six) axes and capacitive sensors; Parallel I/O interface for fast, digital commands PIO	E-712.3CD (E-712.6CD)	E-712.M1*	E-712.R1*	E-711.IP	E-711.SC3H*	E-711.AL4P*	(E-711.SC3H)*	(E-711.AL4P)*
Nanopositioning systems with voltage requirement of up to +120 V with 3 (six) axes and capacitive sensors and long distance between positioner and controller.		E-712.M1	E-712.R1	E-711.IA4 or E-711.IP optional	E-711.0CT	E-711.AL4P	(E-711.0CT)	(E-711.AL4P)
Nanopositioning systems with voltage requiremen ±250 V (PICOCUBE®) with up to 3 axes and capacitive sensors	E-712.3CM	E-712.M1*	E-712.R4*	E-711.IA4 or E-711.IP optional	E-711.SC3H*	E-711.AM4*	–	–
Nanopositioning systems with voltage requirement of up to +120 V with three (six) and incremental sensors		E-712.M1	E-712.R1	E-711.IA4 or E-711.IP optional	E-711.SA3 (E-711.SA6)	E-711.AL4P	–	(E-711.AL4P)
NEXLINE® positioning system with single-axis, incremental sensors and analog interfaces or PIO (optional)		E-712.N1**	E-712.R4	E-711.IA4 or E-711.IP optional	E-711.SA3	E-711.AM4	–	–
NEXLINE® positioning system with 3 axes (combined stepping drive), inkremental sensors and analog interfaces or PIO (optional)		E-712.N1**	E-712.R4	E-711.IA4 or E-711.IP optional	E-711.SA3	E-711.AM4	–	–
NEXLINE® positioning system with 3 axes (combined stepping drive), capacitive sensors and analog interfaces or PIO (optional)		E-712.N1**	E-712.R4	E-711.IA4 or E-711.IP optional	E-711.SC3	E-711.AM4	–	–

* The modul is already included.
** The single- or 3-channel NEXLINE® operation is adjustable via software commands.

E-712 Digital Nanopositioning Controller

Modular System for up to 6 Axes with Highest Precision



Example for the modular use of an E-712 for the vertical and tilt system with three mixed, hybrid drives. They consist of NEXLINE® linear actuators with additional PICMA® actuators for an increased fine adjustment range.

The E-712 digital piezo controller is ideal when it comes to meeting the most demanding accuracy and dynamic-performance requirements of multi-axis nanopositioning systems. The high-performance, real-time operating system makes possible coordinated servo-control of multiple axes (also in parallel-kinematics systems) and thus ensures excellent trajectory control even during complex motion. The modular design allows flexible confection of systems supporting the number of axes and channels required for the application. Flexibility in meeting customers' needs is also behind the interface design: The optional analog inputs and outputs support processing external sensor or control signals as well as driving external amplifiers.

Digital Linearization and Control Algorithms for Highest Accuracy

Linearization algorithms based on higher-order polynomials improve the positioning accuracy to better than 0.01% for capacitive sensors, typically 10 times better than achievable with conventional controllers.

More than just a Controller—Trajectory Control and Data Recording

During fast periodic motion, as typical for scanning applications, the tracking accuracy can be further improved with Dynamic Digital Linearization (DDL, E-710.SCN). This optionally available control algorithm reduces the tracking error by a factor of up to 1000 and enables the spatial and temporal tracking during a dynamic scan. The integrated wave generator can output periodic motion profiles. In addition to sine and triangle waves, arbitrary, user-defined motion profiles can be created and stored. The flexibly configurable data recorder enables simultaneous recording and read-out of the corresponding data.

Flexible Analog Inputs and Real-time PIO

Each of the four optionally available analog inputs can be configured in two ways. When used as a control input, the applied voltage is linked to one of the axes, for target value settings, for example. When configured as an external sensor input, additional sensor signals e.g. for auto-focusing, can be read in. Alternatively, the system can be equipped with a fast 32-bit PIO (Parallel I/O) for placing commands. The PIO supports a restricted command set required for the motion with 100,000 read and write commands per second.

Simple System Integration

All parameters can be checked and reset via software. System setup and configuration is done with the included NanoCapture™ and PIMikroMove™ user-interface software. Interfacing to custom software is facilitated with included LabVIEW drivers and DLLs. System programming is the same with all PI controllers, so controlling a system with a variety of different controllers is possible without difficulty.

Ordering Information

E-712.3CD
Modular Digital Multi-Channel Piezo Controller, 3 Channels, Capacitive Sensors

E-712.3CDA
Modular Digital Multi-Channel Piezo Controller, 3 Channels, Capacitive Sensors, Analog INs and OUTs

E-712.6CD
Modular Digital Multi-Channel Piezo Controller, 6 Channels, Capacitive Sensors

E-712.6CDA
Modular Digital Multi-Channel Piezo Controller, 6 Channels, Capacitive Sensors, Analog INs and OUTs

These models have RS-232, USB and TCP/IP Interfaces.

Further Interfaces are available:

E-711.IA4
Analog Interface Module, 4 I/O for E-712 modular, digital, Controller System

E-711.IP
PIO Interface Module for E-712 modular, digital, Controller System

Ask about custom designs!

Options and Accessories:

E-710.SCN
DDL (Dynamic Digital Linearization) Firmware Upgrade

E-711.i1B
Analog Cable for Analog I/O, BNC Connector, 1.5 m

E-711.i10
Analog Cable for Analog I/O, Solderable End, 1.5 m

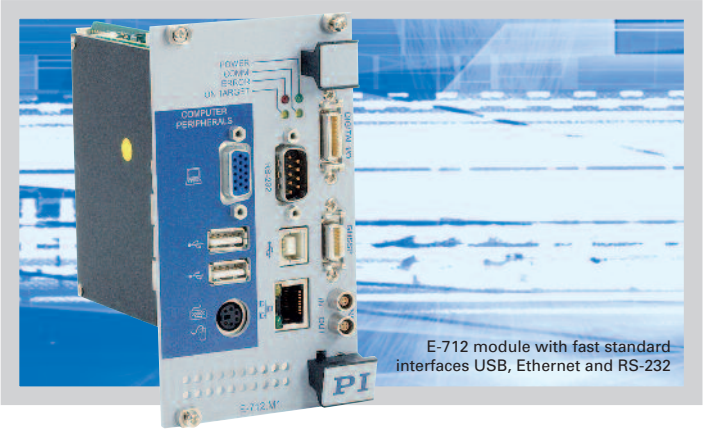
Examples of the modular use of one E-712 for a mixed operation of low voltage and medium voltage actuators (120 V or ±250 V). The positioning system has two separate axis systems for the adjusting and actual measurement process in an inspection system.

Technical Data

Model	E 712.3CD	E 712.6CD	E-712.3CM
Function	Modular digital controller for multi-axis piezo nanopositioning systems with capacitive sensors	Modular digital controller for multi-axis piezo nanopositioning systems with capacitive sensors	Modular digital controller for PicoCube® nanopositioning systems with capacitive sensors
Axes	3	6	3
Processor	PC-based, 600 MHz, real-time operating system	PC-based, 600 MHz, real-time operating system	PC-based, 600 MHz, real-time operating system
Sampling rate, servo-control	50 kHz	20 kHz	50 kHz
Sampling rate, sensor	50 kHz	20 kHz	50 kHz
Sensor			
Servo characteristics	P-I, two notch filters	P-I, two notch filters	P-I, two notch filters
Sensor type	Capacitive	Capacitive	Capacitive
Sensor channels	3	6	3
Sensor bandwidth (-3 dB)	10 kHz	10 kHz	10 kHz
Sensor resolution	18 Bit	18 Bit	18 Bit
Ext. synchronization	Yes	Yes	Yes
Amplifier			
Output voltage	-30 V to +135 V	-30 V to +135 V	-250 V to +250 V
Amplifier channels	4	8	4
Peak output power per channel	25 W	25 W	45 W
Average output power per channel	8 W	8 W	15 W
Peak current	250 mA	250 mA	180 mA
Average current per channel	100 mA	100 mA	60 mA
Current limitation	Short-circuit-proof	Short-circuit-proof	Short-circuit-proof
Resolution DAC	20-bit	20-bit	20-bit
Interfaces and operation			
Communication interfaces	Ethernet, USB, RS-232	Ethernet, USB, RS-232	Ethernet, USB, RS-232
Piezo / sensor connector	Sub-D special connector	Sub-D special connector	Sub-D special connector
Analog in/out	optional je 4 x LEMO, ±10 V (E-711.IA4)	optional je 4 x LEMO, ±10 V (E-711.IA4)	optional je 4 x LEMO, ±10 V (E-711.IA4)
Digital in/out	MDR20; 2 x IN, 8 x OUT; TTL	MDR20; 2 x IN, 8 x OUT; TTL	MDR20; 2 x IN, 8 x OUT; TTL
Command set	PI General Command Set (GCS)	PI General Command Set (GCS)	PI General Command Set (GCS)
User software	NanoCapture™, PIMikroMove®	NanoCapture™, PIMikroMove®	NanoCapture™, PIMikroMove®
Software drivers	LabVIEW Drivers, DLLs	LabVIEW Drivers, DLLs	LabVIEW Drivers, DLLs
Supported functionality	Wave gen, trigger I/O	Wave gen, trigger I/O	Wave gen, trigger I/O
Display	LEDs for OnTarget, Err, Power	LEDs for OnTarget, Err, Power	LEDs for OnTarget, Err, Power
Linearization	4th order polynomials, DDL-Option (Dynamic Digital Linearization)	4th order polynomials, DDL-Option (Dynamic Digital Linearization)	4th order polynomials, DDL-Option (Dynamic Digital Linearization)
Miscellaneous			
Operating temperature range	5 to 50 °C	5 to 50 °C	5 to 50 °C
Overtemp protection	Max. 75°C, of the piezo voltage output	Max. 75°C, deactivation of the piezo voltage output	Max. 75°C, deactivation of the piezo voltage output
Mass	5.35 kg	5.78 kg	5.43 kg
Dimensions	9,5" chassis, 236 x 132 x 296 mm + handles (47 mm length)	9,5" chassis, 236 x 132 x 296 mm + handles (47 mm length)	9,5" chassis, 236 x 132 x 296 mm + handles (47 mm length)
Power consumption	100 W max.	100 W max.	100 W max.
Operating voltage	90 to 240 VAC, 50–60 Hz	90 to 240 VAC, 50–60 Hz	90 to 240 VAC, 50–60 Hz

E-712 Basic Modules

Powerful Processor, Fast Digital Interfaces and Cases



E-712 module with fast standard interfaces USB, Ethernet and RS-232

- **Digital Controller of the Newest Generation: 600 MHz Processor; up to 50 kHz Servo Update Rate**
- **Versions for Conventional Nanopositioning and NEXLINE® Piezo Linear Drives**
- **Real-Time Operating System for Excellent Trajectory Control**
- **Flexible Interfaces: Ethernet, USB, RS-232**

The modular E-712 digital controller is the platform for the most demanding nanopositioning applications. The basic elements of the modular concept are the casing (E-712.R1 or E-712.R4) and the CPU (E-712.M1 or E-712.N1). Further components are available such as different amplifiers, signal conditioners and additional interfaces from the E-711 range.

How many axes would you like?

For special applications, up to 13 channels can be operated in a 19" chassis (482 mm). Conventional applications with up to 6 axes can be fitted into compact 9.5" (241 mm) casings. The casings are equipped with power supplies to suit the type of drive: The E-712.R1 is designed for conventional nanopositioning with low-voltage actuators with up to 6 axes. The E-712.R4 is designed for up to 3 NEXLINE® drives or PicoCube® AFM scanners.

Adjusting the stepping motion of a drive allows operating modes from fast stepping or a constant speed mode to the purely analog shear operation. As an alternative to operating one individual drive, the same E-712 controller can also operate nanopositioning systems with three NEXLINE® drives in coordination.

The Hard Core

The E-712 is PC based. Its computing power is designed for processing times by having a servo update rate of up to 50 kHz, for example. In addition, algorithms for linearization, control, to transform coordinates or store trajectory information are carried out in real time. Even for dynamic applications, the position can thus be achieved with an accuracy of a few nanometers, for example. The varying requirements placed on the motions mean

Ordering Information

For conventional nanopositioning systems with PICMA® low voltage piezo actuating or for PicoCube™

E-712.M1
Digital Computer and Interface Module E-712 with Ethernet Interface, USB, RS-232

E-712.R1
Digital Modular Piezo Controller System, 3 to 6 Channels, 9,5" Chassis with P/S

E-710.SCN
DDL (Dynamic Digital Linearization) Firmware Upgrade

E-712.U1
Advanced Piezo Control Option

E-712.U2
Firmware Upgrade PicoPlane™: Option for Nanometer Precision (convenient hardware required)

E-712.U3
Real-Time System Upgrade for Host PC

For NEXLINE® linear drives:

E-712.N1
Digital NEXLINE® Processor and Interface Module E-712 with Ethernet Interface, USB, RS-232

E-712.R4
Digital Modular Piezo Controller System, 3 to 6 Channels, 9.5" Chassis with Power Supply for ±250 V Piezo Voltage

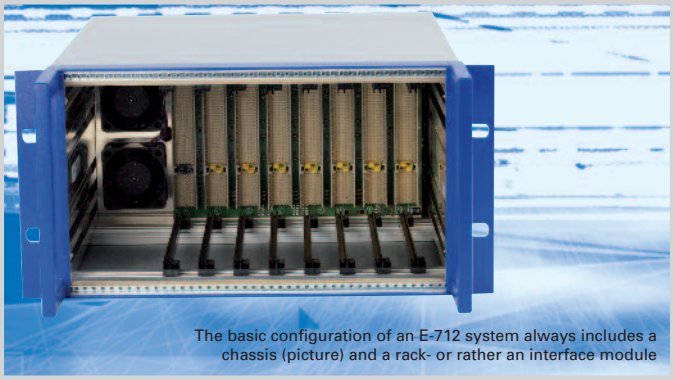
Ask about custom designs!


Custom design of an E-712 system in a 19" chassis for multi-combined piezo actuators and drives

there is a different computer module for nanopositioning applications with conventional ceramic actuators and NEXLINE® Walk Drives.

Modern Interfaces

The computer module offers USB, RS-232 and a fast Ethernet interface as standard. The system can further be supplemented with an analog interface module or a very fast 32-bit PIO.



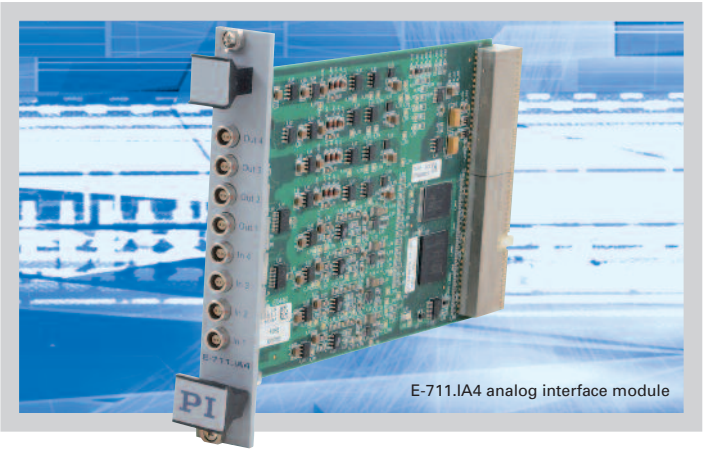
The basic configuration of an E-712 system always includes a chassis (picture) and a rack- or rather an interface module

Technical Data

Model	E-712.M1	E-712.N1
Function	Digital NanoAutomation processor- and interface module with Ethernet Interface, USB Interface, RS-232	Digital NEXLINE® processor- and interface module with Ethernet Interface, USB Interface, RS-232
Processor	PC based, 600 MHz, real-time operating system	PC based, 600 MHz, real-time operating system
Sample rate control (max.)	50 kHz	50 kHz
Sample rate sensor (max.)	50 kHz	50 kHz
Sensor characteristics	P-I, two notch filters or advanced piezo control, optional	P-I, two notch filters
Temperature sensor	Yes	Yes
Interfaces and operation		
Communication interfaces	RS-232, USB, Ethernet (FTP, UDP, HTTP, TCP/IP)	RS-232, USB, Ethernet (FTP, UDP, HTTP, TCP/IP)
Digital Input	MDR 20, 2 x IN, TTL	MDR 20, 2 x IN, TTL
Digital Output	MDR 20, 8 x OUT, TTL	MDR 20,8 x OUT, TTL
Command set	PI General Command Set (GCS)	PI General Command Set (GCS)
User software	PI MikroMove™ , NanoCapture™	PI MikroMove™ , NanoCapture™
Software drivers	LabVIEW Driver, DLLs	LabVIEW Driver, DLLs
Supported functionality	Wave generator, data recorder, trigger I/O	data recorder, trigger I/O
Display	LEDs for OnTarget, Error, Power	LEDs for OnTarget, Error, Power
Linearization	4th order polynomials, DDL Option (Dynamic Digital Linearization)	4th order polynomials; linearization stepping drive
Miscellaneous		
Operating temperature range	5 to 50 °C	5 to 50 °C
Overtemp protection	max. 75 °C, deactivation of the piezo voltage output	max. 75 °C, deactivation of the piezo voltage output
Dimensions	12 TE 3 HE	12 TE 3HE
Mass	0.52 kg	0.52 kg
Operating voltage	90 to 240 VAC; 50–60 Hz	90 to 240 VAC; 50–60 Hz

E-712 Analog Interface Module

Command and Readout in Real-Time



E-711.IA4 analog interface module

Ordering Information

E-711.IA4
Analog Interface Module, 4 I/O

Accessories:

E-711.i1B
Analog Cable for Analog I/O, BNC Connector, 1.5 m

E-711.i10
Analog Cable for Analog I/O, Solderable End, 1.5 m

Ask about custom designs!

- **4 Analog Inputs**
- **4 Analog Outputs**
- **20-bit DA-Converter**
- **18-bit AD-Converter**
- **Powerful FPGA**
- **Smallest Possible Latency**
- **Integrated Self-Testing**

The analog interface module for the E-712 digital controller system offers an additional option for the placing of commands and read-out of 4 channels.

Setting the Target Value in Real-Time

Depending on the application, the target value can be set in the form of an analog voltage, from an autofocus routine or an automation environment, for example. These signals can be read-in directly via the analog E-711.IA4 interface module and used to command an axis. It is therefore not necessary to convert them into a digital signal at the host; this process, which depends on the host operating system, does not therefore cause a delay.

The high resolution of up to 18 bit and the operating system of the E-712 controller allow the input signal to be processed in real time.

Analog Data Output

The data output is also done via the analog interface in 16-bit resolution. The analog output can be configured so that it can directly output the sensor values or the controlled position settings. The latter is useful if the signal is to be used as the input of external power amplifiers, for example.

Digital Real-Time Interface

A further option for fast signal transmission is the use of the fast parallel 32 bit interface (PIO). This is available as the option E-711.IP.

Technical Data

Model	E-711.IA4
Function	Analog Interface Module
Channels	4 In-, 4 Outputs
Resolution Input	18-bit
Resolution Output	16-bit, 20-bit effective
Analog Input	4 LEMO, ±10V
Analog Output	4 LEMO, ±10V
Dimensions	4 TE 3 HE
Mass	0.16 kg

E-712 Parallel-I/O Interface Modules

Fast, Digital Command in Real-Time

E-711.IP 32-bit PIO interface

- **32-bit Resolution**
- **Configured for up to 6 Axis**
- **Fast Communication with 500 ns Read and 1200 ns Write**
- **Optional Real-Time System**

Ordering Information

E-711.IP
PIO Interface Module for E-712 modular, digital, Controller System

E-712.U3
Real-Time System Upgrade for Digital Piezo Controller

Ask about custom designs!

Fast parallel interfaces (PIO) are used where the speed of transmission via the digital standard interface is not sufficient. The PIO supports a restricted command set required for the motion with up to 2 million read or write commands per second.

Real-Time Operating System as an Optional Extra

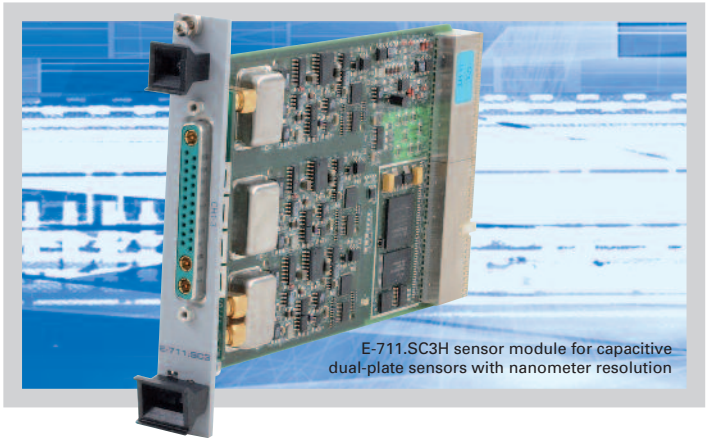
The limiting factor when networking several devices in one application is not necessarily the speed of the interface, but often the operating system as well. For such cases, PI offers a software upgrade to use a real-time operating system on the host computer. The system can be booted on the host PC or as a live version directly from a data carrier. The fully functional real-time system is based on real-time Linux and allows the PI Controller to be controlled via the PIO interface. A PI GCS (General Command Set) library is used for the communication. It supports all user software supplied by PI for Linux and also the integration of additional data acquisition cards and the programming of your own control algorithms, e.g. in C++ or MATLAB/SIMULINK.

Technical Data

Model	E-711.IP
Function	PIO Interface module
Resolution	32-bit
Communication interfaces	HD-Sub-D 62 connector
Speed of command	500 ns read / 1200 ns write
Supported functionality / software drivers	Optional Linux-based real-time system (E-712.U3)
Dimensions	4 TE 3 HE
Mass	0.15 kg

E-712 Sensor Modules

High-Resolution and Solid for Capacitive and Incremental Sensors



E-711.SC3H sensor module for capacitive dual-plate sensors with nanometer resolution

- **Flexible Choice of Sensor Analysis, depend on Positioning Mechanic**
- **For capacitive Dual- or Single-Plate Sensors or incremental Sensors**
- **Resolution of a few Nanometers up to the Sub-Nano Region**
- **Up to 6 Channels**

Ordering Information

E-711.SC3H
Module for Capacitive Sensors, 3 Channels, for E-712 modular, digital, Controller System

E-711.0CT
Digital Sensor Signal Transmission, 3 Channels, Capacitive Sensors, for E-712 Digital Controller

E-711.SE3
Module for PISeca™ Capacitive Single-Electrode Sensors, 3 Channels, for E-712 modular, digital, Controller System

E-711.SA3
Module for incremental Sensors, 3 Channels, for E-712 modular, digital, Controller System

E-711.SA6
Module for incremental Sensors, 6 Channels, for E-712 modular, digital, Controller System

Ask about custom designs!

The choice of sensor module depends on the type of sensor used in the positioning system. For high stability and resolutions in the region of a few nanometers and lower, PI prefers to use 2 types of position sensor: capacitive or incremental ones.

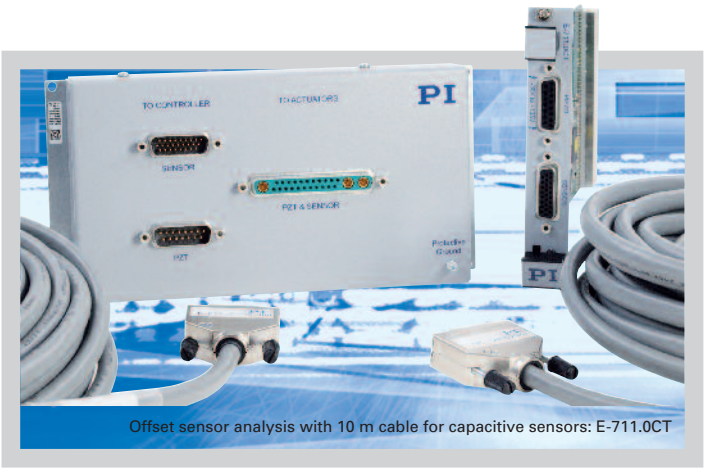
Capacitive Sensors

PI's proprietary capacitive sensors measure position directly and without physical contact. They are free of friction and hysteresis, a fact which, in combination with the positioning resolution of well under 1 nm, makes it possible to achieve very high levels of linearity. Further advantages of direct metrology with capacitive sensors is the high phase fidelity and the high bandwidth of up to 10 kHz.

Capacitive sensors can have two configurations: One and two-electrode sensors. PI usually uses two-electrode sensors in its nanopositioning systems. PISeca™ one-electrode sensors are available as external sensors. Capacitive sensors measure absolute position.

Large Distances between Controller and Stage

An application where the positioning system with capacitive sensors and the controller are more than 3 meters apart requires digital, interference-free transmission of the sensor signal. The sensor evaluation is done in a separate instrument positioned close to the positioning system where the sensor signal is digitized with 18-bit resolution and transmitted to the controller. This type of transmission works over distances of up to 30 meters, a 10-meter cable is included with the option E-711.0CT.



Offset sensor analysis with 10 m cable for capacitive sensors: E-711.0CT

Incremental Encoders

Where the travel range is typically greater than 1 mm, PI uses incremental sensors (linear or ring encoders). They achieve resolutions of about one nanometer with a linearity of up to 1 % of the grating period. Incremental encoders measure changes relative to a reference position (relative rather than absolute).

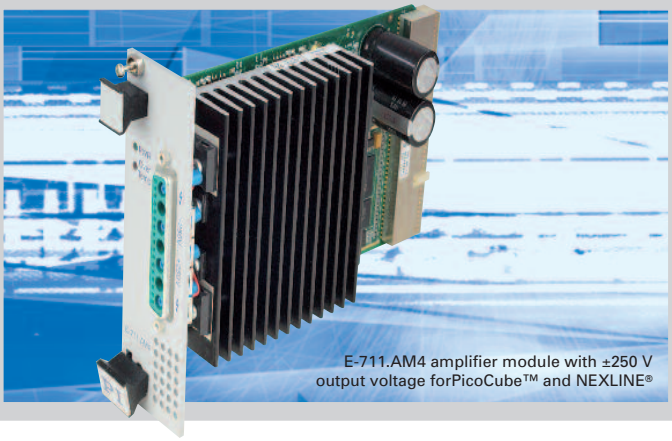
PISeca™ capacitive single-electrode sensors. Easy assembly and High-Precision qualified these sensors for measurements of distances and motions

Technical Data

Model	E-711.SC3H	E-711.0CT	E-711.SE3	E-711.SA3
Function	Modul for capacitive sensors	Module for capacitive sensors with sensor analysis (DST)	Module for capacitive PISeca™ single-electrode sensors	Module for incremental sensors
Channels	3	3	3	3
Sensor type	capacitive	capacitive	Single-electrode, capacitive	incremental
Sensor bandwidth	10 kHz	10 kHz		
Sensor resolution	18-bit	18-bit	18-bit	16-bit
Sensor communication	Sub-D Special (multi-axis, capacitiv)	Sub-D Special (multi-axis, capacitiv), 10 m cable length between sensor analysis and controller	Sub-D Special (multi-axis, capacitiv)	Sub-D Special
Dimensions	4 TE 3 HE	4 TE 3 HE; Sensor analysis 198.5 x 102.9 x 38.3 mm	4 TE 3 HE	4 TE 3 HE
Mass	0.18 kg	Sensor analysis: 0.65 kg Interfacekarte: 0.15 kg	0.18 kg	0.15 kg

E-712 Amplifier Modules

High-Power and Low-Noise for Dynamic and Precision



E-711.AM4 amplifier module with ±250 V output voltage forPicoCube™ and NEXLINE®

- **Flexible Opions for Nanopositioning, PicoCube™ and NEXLINE® Drives**
- **4 Channels**
- **High-Voltage, 8 W per Channel**
- **Highest Stability, Low Noise**
- **20-bit Effective**
- **Powerful FPGA**

The amplifier modules are designed to operate all piezoceramic drive systems used by PI for nanopositioning on the basis of the E-712 digital controller system.

PICMA® Based Nanopositioning Technology

Conventional positioning systems use the direct displacement of the piezoceramics for the movement. PI uses the reliable PICMA® high performance actuators for this in a typical voltage range of between -20 and +120 V.

PicoCube™ AFM-Scanner

Based on PICAShear™ actuators, the PicoCube™ scanners offer maximum resolution and dynamics up to the kilohertz region. The shear actuators used are operated in a voltage range between -250 and +250 V.

NEXLINE® with Long Travel Range

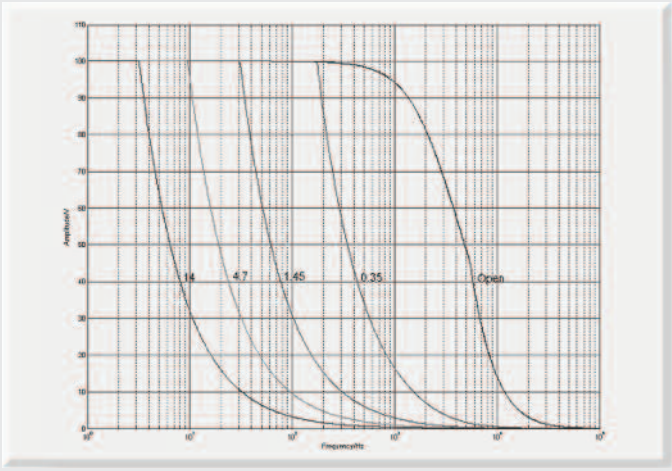
NEXLINE® linear drives offer maximum precision and stiffness over long travel ranges. The PiezoWalk® walking drive principle is based on shear actuators with a voltage range of between -250 and +250 V.

Ordering Information

E-711.AL4P
High-Power Amplifier Module, 3 Channels, 8 W, for E-712 modular, digital, Controller System

E-711.AM4
Amplifier module forPicoCube™, 3 Channels, for E-712 modular, digital, Controller System, -250 V bis +250 V

Ask about custom designs!



E-712 operating limits with various capacitive loads, capacitance is measured in µF

Technical Data

Model	E-711.AL4P	E-711.AM4	Units
Function	High-Power amplifier module, 8 W, -30 bis +135 V	Amplifier module, ±250 V	
Channels	4	4	
Output Voltage min.	-30	-250	V
Input Voltage max.	135	250	V
Peak output power per channel	25	45	W
Average output power per channel	8	15	W
Peak current per Channel	250	180	mA
Average current per channel	100	60	mA
Current limitation	Short-circuit-proof	Short-circuit-proof	
Resolution DAC	20	20	bit
Dimensions	8 TE 3 HE	8 TE 3 HE	
Mass	0.48	0.48	kg

Interfaces

Digital Interfaces

Digital or Analog Interfacing?

Analog interfacing provides high bandwidth and remains the most common way of commanding piezoelectric motion systems. It is usually the choice when the control signal in the application is provided in analog form. A key advantage of analog interfacing is its intrinsic deterministic (real-time) behavior, contrasted to the difficulty of accurately timing high-bandwidth communications on present-day multitasking PCs.

However, when analog control signals are not available, or when a significant distance between the control signal source and the nanopositioning controller would affect signal quality, digital interfacing, which must not be confused with digital control, is the preferred choice.

Digital signals can be transferred through copper wires, or for complete EMI immunity, through optical fibers.

Supported Digital Interfaces

PI's controllers are equipped with fast TCP/IP, USB and RS-232 interfaces (for details and exceptions see data sheets). Positioning commands can be formulated directly in SI units (e.g. microns and microradians), a feature which facilitates programming the system. In addition, parameters for the servo-loop, low-pass and notch filters are easily optimized and can be stored in non-volatile memory.

An optional parallel interface (PIO) bypasses the command parser and allows reading and writing up to 20,000 positions per second. Fast PCI interfaces offer transfer rates up to 1 MHz.

Interface Bandwidth vs. Timing

Piezo-driven stages can respond to a motion command on a millisecond or microsecond time scale.

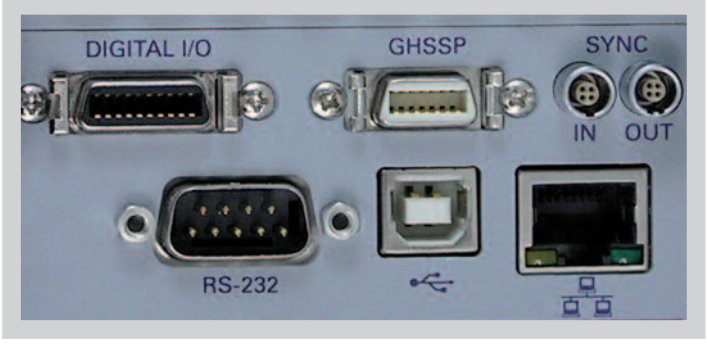
That is why synchronization of motion commands and data acquisition have a high impact on the quality of many applications, like imaging or micromachining. The USB, for example, was designed to transfer huge blocks of data at high speeds, but exact timing was a much lesser concern. While insignificant in less responsive positioning systems, this kind of non-deterministic behavior may not be tolerable in high-speed tracking or scanning applications. Each motion command—comprising just a few bytes—must be transferred instantaneously and without latency. A lower-bandwidth bus with higher timing accuracy may perform better in many applications.

There are several factors that affect the response of a digital interface: the timing accuracy of the operating system on the controlling computer; the bus timing protocol; the bandwidth of the bus; and, the time it takes the digital interface (in the piezo controller) to process each command. Parallel-port interfaces do not require command parsing and offer the best combination of throughput and timing accuracy.

In addition to the interface properties, the bandwidth of the nanopositioning system (mechanics and servo) matters. A slow system (e.g. 100 Hz resonant frequency) will not benefit from a responsive interface as much as a high-speed mechanism.

Speed Comparison

E-712 Nanopositioning controller	
MOV Commando	
RS-232	1.73 ms
TCP/IPt	0.07 ms
USB	0.13 ms
POS Query	
RS-232	2.57 ms
TCP/IPt	0.40 ms
USB	0.63 ms



PI controllers are available with a number of different interfaces for highest flexibility. In addition to the modern Ethernet (TCP/IP) and USB, many industrial customers still appreciate the robust RS-232 protocol.

E-712.U3 Real-Time Upgrade: Real-time operating system for system integration

The use of real-time operating systems on the host PC avoids time delays when communicating with other system components, e.g. a vision system. PI offers a real-time Linux-based operating system as an upgrade for the host PC and also the linking of the GCS (PI General Command Set) software drivers to this operating system.

- A library which is 100 % compatible with all other PI GCS libraries is used for the communication with the real-time system. All PI GCS host software available for Linux can be run on this system.
- The real-time system running in the real-time CPU links PI interfaces and additional data acquisition cards for control. Open functions to enable you to implement your own control algorithms are made available. Furthermore, there is the possibility to record data, such as positions and voltages, from the PI interfaces and the additional data acquisition cards in real time, and also to output predefined tables with positions, for example, in real time to the PI interfaces and the additional data acquisition cards.
- The programming of your own real-time functions can be carried out in C/C++, MATLAB/SIMULINK and SCILAB.
- The system includes a PI GCS server, which allows the system to be operated as a blackbox using TCP/IP, via a Windows computer, for example.
- The system can be booted when installed on a PC or as a live version directly from the data carrier.
- A free demo version with restricted functionality is available.

E-761 Digital Piezo Controller

Cost-Efficient PCI Board for Piezo Stages with up to 3 Axes

E-761 Digital Piezo Controller in PCI-Board Format

- **For Piezo Stages with Capacitive Sensors**
- **High-Speed PCI Interface**
- **3 Logical Axes, 4 Piezo Amplifiers**
- **Additional High-Bandwidth Analog Interface**
- **32-Bit Digital Filters**
- **Notch Filter for Higher Bandwidth**
- **24-Bit Ultra-Low-Noise DAC Converters**
- **Auto-Loading of Calibration Data from Stage ID-Chip for Interchangeability of Controller and Mechanics**
- **Coordinate Transformation for Parallel-Kinematics / Parallel-Metrology Systems**
- **Extensive Software Support**

E-761 digital piezo controllers offer advanced control technology in a cost-effective PCI-board format. They were designed to run piezo stages with up to three logical axes. The E-761 incorporates four instrumentation-class, 24-bit digital-analog converters (DAC) behind ultra-low-noise power amplifiers, and is based on a specialized 32-bit digital signal processor (DSP) with proprietary firmware.

Having PCI-board format, the E-761 digital controller can be easily installed in any commercial or industrial PC, allowing for easy integration with other devices such as frame grabbers. The PCI interface with its high bandwidth makes possible a very fast communication between software and controller. This is a definite plus in time-critical applications or when controlling several axes.

Additionally, the E-761.3CT version offers three digital output lines for a variety of triggering tasks.

Improved Trajectory Accuracy Through Parallel Metrology

Digital controllers have a number of advantages over conventional analog piezo controllers. Sensor and actuator axes need not be parallel to each other, or to the orthogonal logical axes used to command the system. The flexible coordinate transformation algorithm permits operation of complex, multi-axis, parallel metrology stages (e. g. 3-axis Z-tip-tilt-stages).

With parallel motion metrology, the controller compensates the undesired off-axis motion of each actuator automatically using the others (active trajectory control). High-end nanopositioning systems with active trajectory control can attain motion accuracies in the sub-nanometer range.

Digital Linearization and Control Algorithms for Highest Accuracy

Linearization algorithms based on higher-order polynomials improve the positioning accuracy to 0.001 % of the travel range.

During fast periodic motion, as typical for scanning applications, the tracking accuracy can be further improved with Dynamic Digital Linearization (DDL, E-710.SCN). This optionally available control algorithm reduces the tracking error by a factor of up to 1000.

The integrated wave generator can save and output periodic motion profiles. In addition to sine and triangle waves, arbitrary, user-defined profiles can be created.

Automatic Configuration

PI digital piezo controllers and nanopositioning stages with ID-chips can be operated in any combination, supported by the controller's AutoCalibration function. Individual stage data and optimized servo-control parameters are stored in the ID-Chips and are read out automatically by the digital controller.

Simple System Integration

All parameters can be set and checked by software. System setup and configuration is done with the included NanoCapture™ and PZTControl™ user-interface software. Interfacing to custom software is facilitated with included LabVIEW drivers and DLLs. All PI controllers use the same command set, a significant advantage during application software development, system upgrade or when operating a variety of different controllers from one application.

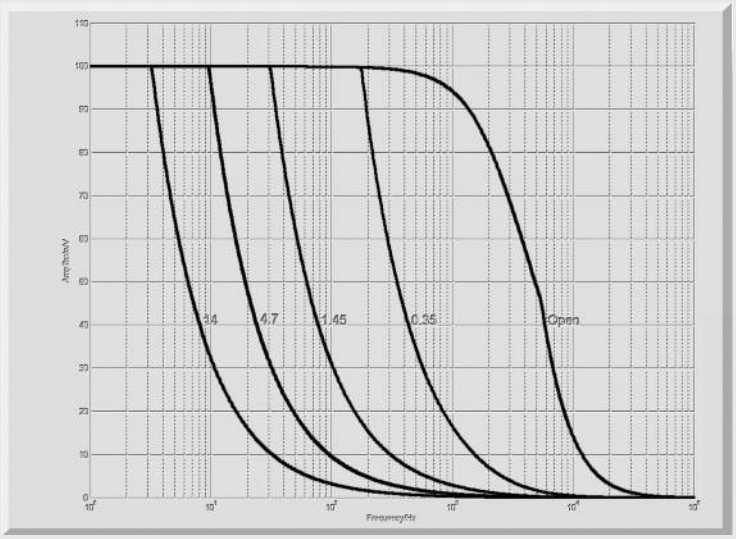
Ordering Information

E-761.3CD
Digital Piezo Nanopositioning Controller, 3 Axes, Sub-D-Special, PCI Board

E-761.00T
Trigger Output Bracket for E-761.3CD

E-761.3CT
Digital Piezo Nanopositioning Controller, 3 Axes, Sub-D-Special, PCI Board, Trigger Output

Ask about custom designs!



E-761: operating limits with various PZT loads (open-loop), capacitance is measured in µF

Technical Data

Model	E-761.3CD	E-761.3CT
Function	Digital piezo controller and power amplifier, PCI board	Digital piezo controller and power amplifier, PCI board, trigger output
Axes	3	3
Processor	32-bit, floating-point DSP	32-bit, floating-point DSP
Sampling rate, servo-control	40 µs / 25 kHz (sensor-oversampling factor 4)	40 µs / 25 kHz (sensor-oversampling factor 4)
Sensor		
Servo characteristics	P-I, two notch filters	P-I, two notch filters
Sensor type	Capacitive	Capacitive
Sensor channels	3	3
Sensor resolution	16-bit	16-bit
Ext. synchronization	Yes	Yes
Amplifier		
Output voltage	-20 to 120 V	-20 to 120 V
Amplifier channels	4	4
Peak output power per channel,	5.3 W	5.3 W
Average output power per channel	1.7 W	1.7 W
Peak current per channel, <20 ms	50 mA	50 mA
Average current per channel, >20 ms	10 mA	10 mA
Current limitation	Short-circuit-proof	Short-circuit-proof
Resolution DAC	24-bit	24-bit
Interfaces and operation		
Interface / communication	PCI connector	PCI connector
Piezo / sensor connector	Sub-D special	Sub-D special
Control Input sockets	LEMO	LEMO
Digital output	-	3 x TTL
Command set	GCS	GCS
User software	NanoCapture™, PZTControl™	NanoCapture™, PZTControl™
Software drivers	LabVIEW drivers, Windows and Linux Libraries (DLL)	LabVIEW drivers, Windows and Linux Libraries (DLL)
Supported functionality	Wave generator	Wave generator, trigger output
Display	Status LED for piezo voltage	Status LED for piezo voltage
Linearization	4th order polynomial	4th order polynomial
Miscellaneous		
Operating temperature range	+5 to +50 °C (derated 10 % over 40 °C)	+5 to +50 °C (derated 10 % over 40 °C)
Overtemp protection	Deactivation at 60 °C	Deactivation at 60 °C
Dimensions	287 x 108 x 25 mm (2 slots)	287 x 108 x 25 mm + 122 x 45x 26 mm (3 slots)
Mass	0.56 kg	0.56 (PCI-board only)
Operating voltage	5 V	5 V
Power consumption	20 W, 4 A max.	20 W, 4 A max.

E-725 Digital Piezo Controller

For 3-Axis High-Speed Precision Positioning Systems

E-725 Digital 3-channel controller with P-528 Z/tip/tilt nanopositioning system

Ordering Information

E-725.3CD
Digital Multi-Channel Piezo Controller, 3-Channel, Sub-D Connector for Capacitive Sensors

E-725.3CM
Digital Multi-Channel Piezo Controller, for PicoCube™ and Capacitive Sensors

Ask about custom designs!

- **For Nanopositioning Systems with Capacitive Sensors**
- **3-Channel Version**
- **Powerful Digital Controller: DSP 32-bit Floating Point, 225 MHz; 20 kHz Sampling Rate; 24-bit DAC**
- **Communication via Ethernet, USB, RS-232**
- **4th Order Polynomial Linearization for Mechanics & Electronics**
- **Dynamic Digital Linearization (DDL) Option for Improved Path Accuracy**
- **Auto-Loading of Calibration Data from Stage ID-Chip for Interchangeability of Controller and Mechanics**
- **Additional High-Bandwidth Analog Control Input / Sensor Input**
- **Optional High-Speed Parallel I/O Interface**
- **Flexible Wave Generators**
- **Digital I/O Lines for Task Triggering**
- **Extensive Software Support**

The E-725 digital piezo controller is a compact, high-performance drive electronics for nanopositioning systems with up to three axes. High-power amplifiers permit dynamic scans even for piezo systems with large range or direct drive. State-of-the-art processor technology optimizes the operating parameters for improved linearity and tracking accuracy. High-resolution D/A converters provide for nanopositioning that deserves this name.

With the E-725.3CM, PI for the first time offers a digital controller for the P-363 PicoCube™ (see p. 2-66), a fast precision scanner for atomic force microscopy.

Optional interfaces and analog in- and outputs make it possible to process external sensor or control values.

Digital Linearization and Control Algorithms for Highest Accuracy

Linearization algorithms based on higher-order polynomials improve the positioning accuracy to better than 0.01 % for capacitive sensors, typically 10 times better than achievable with conventional controllers.

More than just a Controller – Trajectory Control and Data Recording

During fast periodic motion, as typical for scanning applications, the tracking accuracy can be further improved with Dynamic Digital Linearization (DDL, E-710.SCN). This optionally available control algorithm reduces the tracking error by a factor of up to 1000.

This control algorithm enables the spatial and temporal tracking during a dynamic scan. The integrated wave generator can output periodic motion profiles. In addition to sine and triangle waves, arbitrary, user-defined motion profiles can be created and stored. The flexibly configurable data recorder enables simultaneous recording and read-out of the corresponding data.

Extensive Software Support

The controllers are delivered with Windows operating software. Comprehensive DLLs and LabVIEW drivers are available for automated control.

Automatic Configuration

PI digital piezo controllers and nanopositioning stages with ID-Chip can be operated in any combination, supported by the AutoCalibration function of the controller. Individual stage data and optimized servo-control parameters are stored in the ID-Chip and are read out automatically by the digital controllers.

Technical Data

Model	E-725.3CD	E-725.3CM	Tolerance
Function	Digital Controller for Multi-Axis Piezo Nanopositioning Systems with Capacitive Sensors	Digital Controller for Multi-Axis Piezo Nanopositioning Systems with Capacitive Sensors	
Axes	3	3	
Processor	DSP 32-bit floating point, 225 MHz	DSP 32-bit floating point, 225 MHz	
Sampling rate, servo-control	20 kHz	20 kHz	
Sampling rate, sensor	20 kHz	20 kHz	
Sensor			
Servo characteristics	P-I, two notch filters	P-I, two notch filters	
Sensor type	Capacitive	Capacitive	
Sensor channels	3	3	
Sensor bandwidth (-3 dB)	5.6 kHz	5.6 kHz	max.
Sensor resolution	18 bit	18 bit	
Ext. synchronization	Yes	Yes	
Amplifier			
Output voltage	-30 to 135 V	-250 to 250 V	±3 V
Amplifier channels	4	4	
Peak output power per channel	25 W	47 W	max.
Average output power per channel*	10 W	10 W	max.
Peak output current per channel	190 mA	190 mA	max.
Average output current per channel*	120 mA	60 mA	max.
Current limitation	Short-circuit proof	Short-circuit proof	
Resolution DAC	24 bit	24 bit	
Interfaces and operation			
Communication interfaces	Ethernet, USB, RS-232	Ethernet, USB, RS-232	
Piezo / sensor connector	Sub-D special connector	Sub-D special connector	
Analog input	1 x Lemo, ±10 V, 18 bit	1 x Lemo, ±10 V, 18 bit	
Digital input / output	MDR20; 2 x IN, 8 x OUT	MDR20; 2 x IN, 8 x OUT	
Command set	PI General Command Set (GCS)	PI General Command Set (GCS)	
User software	NanoCapture™, PIMikroMove™	NanoCapture™, PIMikroMove™	
Software drivers	LabVIEW driver, DLLs	LabVIEW driver, DLLs	
Supported functionality	Wave-Gen, Trigger I/O	Wave-Gen, Trigger I/O	
Display	LEDs for Power, On Target, Error, Cmd	LEDs for Power, On Target, Error, Cmd	
Linearization	4th order polynomial, DDL (Dynamic Digital Linearization)	4th order polynomial, DDL (Dynamic Digital Linearization)	
Separate protective ground connector	Yes	Yes	
Miscellaneous			
Operating temperature range	5 to 50 °C	5 to 50 °C	
Overheat protection	Max. 71 °C, deactivation of the piezo voltage output	Max. 71 °C, deactivation of the piezo voltage output	
Mass	3.5 kg	3.6 kg	
Dimensions	263 x 89 x 302 mm (with handles)	263 x 89 x 302 mm (with handles)	
Power consumption	70 W	70 W	max.
Operating voltage	24 VDC from external power supply (included)	24 VDC from external power supply (included)	

* The total output power of all 4 amplifier channels should not exceed 34.5 W to avoid overcurrent (E-725 is equipped with a 3.15 AM fuse).

E-753 Digital Piezo Controller

High-Speed, Single-Axis Controller

E-753 Single-channel digital controller together with the PIHera® P-629.1CD nanopositioning stage with 1500 µm travel

- **Next Generation Digital Controller Provides Higher Flexibility, Accuracy and Speed**
- **100 kHz Sensor Sampling; 32-bit Floating Point DSP; 24-bit Low-Noise D/A Converters**
- **Ethernet (TCP/IP) Interface for Remote Control Capability, RS-232**
- **Auto-Loading of Calibration Data from Stage ID-Chip for Interchangeability of Controller and Mechanics**
- **Additional High-Bandwidth Analog Control Input / Sensor Input**
- **Digital I/O Lines for Task Triggering**
- **Extensive Software Support**
- **For Nanopositioning Systems with Capacitive Sensors**

The E-753 next-generation digital piezo controller is the result of PI's 30+ years of experience with piezo motion control systems. It is ideal when it comes to meeting the most demanding accuracy and dynamic-performance requirements of nanopositioning systems of the highest precision class. The E-753 replaces the E-750 controller.

Digital Linearization and Control Algorithms for Highest Accuracy

Linearization algorithms based on higher-order polynomials improve the positioning accuracy to 0.001 % of the travel range. During fast periodic motion, as typical for scanning applications, the tracking accuracy can be further improved with Dynamic Digital Linearization (DDL, E-710.SCN). This optionally available control algorithm reduces the tracking error by a factor of up to 1000 and enables the spatial and temporal tracking during a dynamic scan.

Higher Velocity and Bandwidth for Dynamic Applications

The controller is perfectly suited for high-dynamics operation thanks to its high-resolution DA-converter and high-performance voltage amplifier. The high-speed processor with a sensor sampling rate of 100 kHz assures settling times in the millisecond range and below.

Flexibility for a Variety of Applications

PI nanopositioning systems which are equipped with an ID-chip and calibrated with a digital controller have the mechanics-related calibration and servo-control parameters stored in the chip. The controller automatically adapts to the connected mechanics by the appropriate use of this data, so that recalibration is not necessary when system components are replaced.

The integrated wave generator can save and output periodic motion profiles. In addition to sine and triangle waves, arbitrary, user-defined profiles can be created.

Simple System Integration

All parameters can be checked and reset via software. System setup and configuration is done with the included NanoCapture™ and PIMikroMove™ user-interface software. Interfacing to custom software is facilitated with included LabVIEW drivers and DLLs. System programming is the same with all PI controllers, so controlling a system with a variety of different controllers is possible without difficulty.

Ordering Information

E-753.1CD
High-Speed Single-Channel Digital Piezo Controller for Capacitive Sensors

E-710.SCN
DDL (Dynamic Digital Linearization) Firmware Upgrade

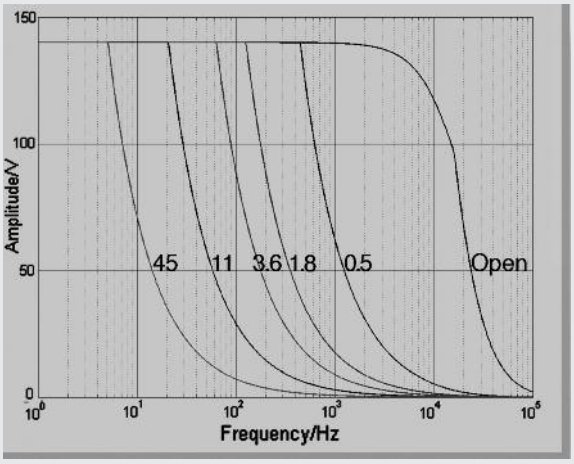
E-753.IO
Cable for Digital I/O Lines, 1.5 m, Solderable End

Ask about custom designs!

P-725 PIFOC® objective Z-positioner and E-753 controller constitute an optimal system for high-speed, high-resolution positioning and scanning.

Technical Data

Model	E-753.1CD
Function	Digital controller for single-axis piezo nanopositioning systems with capacitive sensors
Axes	1
Processor	DSP 32-bit floating point, 60 MHz
Sampling rate, servo-control	25 kHz
Sampling rate, sensor	100 kHz
Sensor	
Servo characteristics	P-I, two notch filters
Sensor type	Capacitive
Sensor channels	1
Sensor bandwidth	5.6 kHz
Sensor resolution	17-bit
Ext. synchronization	Yes
Amplifier	
Output voltage	-30 V to 135 V
Amplifier channels	1
Peak output power <5 ms	15 W
Average output power >5 ms	5 W
Peak current <5 ms	110 mA
Average current >5 ms	40 mA
Current limitation	Short-circuit-proof
Resolution DAC	24-bit
Interfaces and operation	
Communication interfaces	Ethernet, RS-232
Piezo connector	Sub-D special connector
Sensor connection	Sub-D special connector
Analog input	LEMO, ±10 V, 18 bit
Digital input	2 x LEMO, TTL
Digital output	2 x LEMO, TTL
Command set	GCS
User software	NanoCapture™, PIMikroMove™
Software drivers	LabVIEW drivers, DLLs
Supported functionality	Wave generator, trigger I/O, data recorder
Display	Status LEDs
Linearization	4th order polynomials, DDL (optional)
Separate protective ground connector	Yes
Miscellaneous	
Operating temperature range	5 to 50 °C
Overtemp protection	Deactivation of the piezo voltage output at 85 °C
Mass	0.9 kg (controller)
Dimensions	Controller: 264 x 125 x 48 mm (with rubber feet) Power supply: 174 x 95 x 58 mm (with rubber feet)
Power consumption	10 W max.
Operating voltage	24 VDC from external power supply (included)



E-753 open-loop operating limits with various PZT loads. Graphs reflect the large signal-current limitation of the amplifier circuit, not the actual bandwidth.

E-755 Digital NEXLINE® Controller

Controller for Picometer-Precision PiezoWalk® Linear Actuators / Positioners

E-755 digital NEXLINE® controller with N-214 nanopositioner, 20 mm travel range.

- **Special Control Algorithms for NEXLINE® Nanopositioning Linear-Motor Actuators**
- **32-Bit Digital Filters**
- **24-Bit DAC Resolution**
- **Fully Programmable Low-Pass and Notch Filters**
- **Non-Volatile User Settings and Last-Position Data**
- **Daisy-Chain Networking for up to 16 Axes**
- **PI GCS (General Command Set) Compatible**

E-755 digital single-axis nanopositioning controllers are designed to drive the patented NEXLINE® nanopositioning linear drives. Combining advanced control technology and sensor signal processing with special drive algorithms, the E-755 can provide precision motion control over hundreds of millimeters with picometer-range resolution. Coordinated action of shearing and clamping piezo elements is what allows NEXLINE® to break through the barriers of conventional nanopositioning actuators.

The E-755 offers two different control modes for the NEXLINE® walking drives: a high-resolution, high dynamics direct piezo mode, with basically unlimited resolution (analog mode), and a long-range stepping mode with theoretically unlimited travel range.

High-Resolution Servo-Control

E-755 controllers are based on powerful 32-bit DSPs and come in open- and closed-loop versions. Both versions feature four high-resolution (24-bit) linear amplifiers with the output range of ±250 V required to control a single-axis NEXLINE® drive. For the closed-loop models, high-resolution incremental position sensors are supported by special excitation and read-out electronics.

The sensors supported may provide better than nanometer resolution. A power-down routine in the E-755 firmware saves the current position, allowing a closed-loop system to be ready for operation without referencing next time it is powered up.

NEXLINE® Working Principle for Application Flexibility

NEXLINE® PiezoWalk® drives are ideal wherever high loads must be positioned very precisely over long distances and then perhaps subjected to small-amplitude dynamic adjustment, as for active vibration control. By varying the characteristics of the longitudinal and shear piezo elements, the step size, dynamic operating range (analog travel), clamping force, speed and stiffness can all be optimized for a particular application.

NEXLINE® PiezoWalk® piezoceramic clamping and shearing elements act directly on a moving runner that is coupled to the moved part in the application. While the runner can bemoved large distances in step mode, high-dynamics positioning over distances of less than one step is possible with resolutions far below one nanometer in analog mode. The patented PiezoWalk® thus overcomes the limitations of conventional nanopositioning actuators and combines long travel ranges with high resolution and stiffness.

Extreme Actuator Lifetime

To eliminate long-term offset voltages, which limit the lifetime of conventional piezo drives, the E-755 controller uses a special procedure to bring the actuator to a full-holding-force, zero-voltage condition, no matter where it may be along its travel range. Due to the resulting long lifetime, NEXLINE® nanoposition-

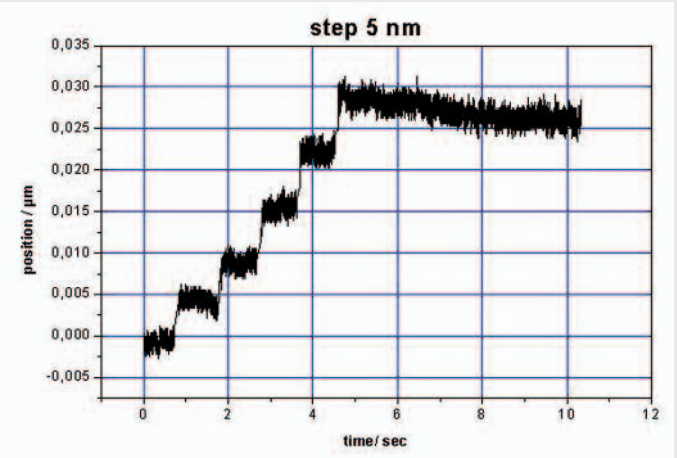
Application Examples

- Semiconductor technology
- Quality assurance testing in semiconductor industry
- Astronomical telescopes
- Truss structures
- Active vibration control
- Alignment in high magnetic fields, as in particle physics, atomic fusion and superconductivity research

Ordering Information

E-755.1A1
Digital Controller for NEXLINE® Nanopositioning Linear Drives, Incremental Sensors

E-755.101
Digital Controller for NEXLINE® Nanopositioning Linear Drives



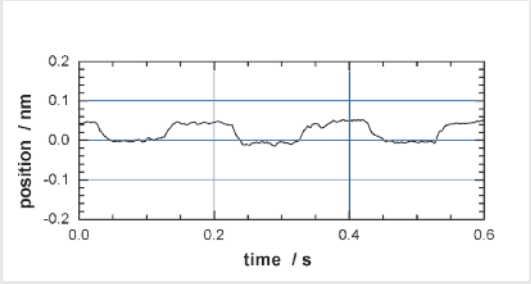
Steps of 5 nm performed by a system consisting of an N-214 NEXLINE® nanopositioner and an E-755.1A1 controller, measured by a high-resolution interferometer. Note the excellent system response to consecutive 5 nm step commands. In this case the closed-loop resolution is limited by the linear encoder in the N-214 (5 nm / increment); the E-755 can work with linear encoders with sub-nanometer resolution

ing actuators are ideal for installation in inaccessible locations deep inside complex equipment, where nanometer-precise alignment and vibration cancellation are required.

Linearization

E-755-controlled nanopositioning systems provide outstanding linearity, achieved by digital polynomial linearization. The linearization can improve linearity to 0.001 % over the full travel range. The products described in this datasheet are in part protected by the following patents:
German Patent No. 10148267
US Patent No. 6,800,984

Six-axis nonmagnetic Hexapod with N-215-based NEXLINE® high-load actuators for use in high magnetic fields. The system is driven by six E-755 controllers and additional hardware/firmware to automatically perform the necessary parallel-kinematics coordinate transformation.



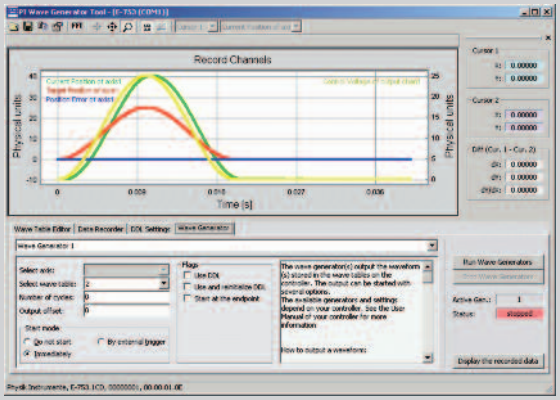
Steps of 50 picometers with a NEXLINE® drive in open-loop mode measured with external, ultra-high-resolution, capacitive sensor

Technical Data

Model	E-755.1A1	E-755.101
Funktion	Digital controller for NEXLINE® nanopositioning linear drives with incremental encoder	Digital controller for NEXLINE® nanopositioning linear drives
Axes	1	1
Processor	DSP 32-bit floating point, 50 MHz	DSP 32-bit floating point, 50 MHz
Sensor		
Sensor channels	1	–
Servo update time	0.2 ms	–
Sensor sampling time	0.1 ms	–
Dynamic cycle time	0.2 ms	0.1 ms
Servo characteristics	P-I, notch filter	–
Sensor type	Incremental sensor	–
Amplifier		
Amplifier channels	4	4
Output voltage	-250 to +250 V	-250 to +250 V
Peak output power per channel	5.5 W	5.5 W
Average output power per channel	3 W, limited by temperature sensor	3 W, limited by temperature sensor
Peak current	44 mA	44 mA
Average current per channel	25 mA, limited by temperature sensor	25 mA, limited by temperature sensor
Current limitation	Short-circuit-proof	Short-circuit-proof
Resolution DAC	24 bit	24 bit
Interfaces and operation		
Communication interfaces	RS-232	RS-232
Piezo connector	Sub-D Special	Sub-D Special
Sensor connector	15-pin sub-D connector	–
Controller network	Daisy-chain, up to 16 units	Daisy-chain, up to 16 units
Command set	GCS	GCS
User software	PIMikroMove™, NanoCapture™ , PITerminal	PIMikroMove™, NanoCapture™ , PITerminal
Software drivers	LabVIEW drivers, DLLs	LabVIEW drivers, DLLs
Supported functionality	NEXLINE® Control algorithms (closed-loop), data recorder, position storage	NEXLINE® Control algorithms (open-loop), data recorder
Display	Status LEDs	Status LEDs
Linearization	4th order polynomial	4th order polynomial
Miscellaneous		
Operating temperature range	5 to 50 °C	5 to 50 °C
Overtemp protection	Deactivation at 70 °C	Deactivation at 70 °C
Dimensions	264 x 260 x 47 mm	264 x 260 x 47 mm
Mass	2.3 kg	2.3 kg
Operating voltage	24 V (power supply included)	24 V (power supply included)
Power consumption	48 W, 2 A max.	48 W, 2 A max.

Advanced Functionality – Requirements from the Applications

Trajectory Storage, Data Recorder, Macros, System Recognition, Autofocus…



Data recorder and wave generator are part of the MikroMove® software for all digital controllers.

Data Recorder: Data Acquisition and Output

The flexibly configurable data recorder enables simultaneous recording and read-out of input and output signals, such as for sensor positions or control voltages depending on time stamps or using trigger signals.

Wave and Profile Generator: Pre-Defined and Programmable Trajectory Profiles

Trajectory profiles of arbitrary, user-defined mathematical functions enable complex 2-axis motion. Depending on the controller used, either time and position data value pairs can be saved (Wave Generator) or complete trajectory profiles with velocity, acceleration and jerk (rate of change of acceleration) can be specified (Profile Generator). The functionality includes:

- Programming of complex functions
- Quick access to common functions (e. g. sine, ramps, triangle and square waves ...)
- Coordination of two axes, e. g. for applications requiring circular motion
- Saving of defined functions in the controller

All controller specific functionalities are available as DLL function calls and LabVIEW VIs, which enables their simple integration in external programs. Additional graphical user interfaces allow convenient selection and customization.

Autofocus

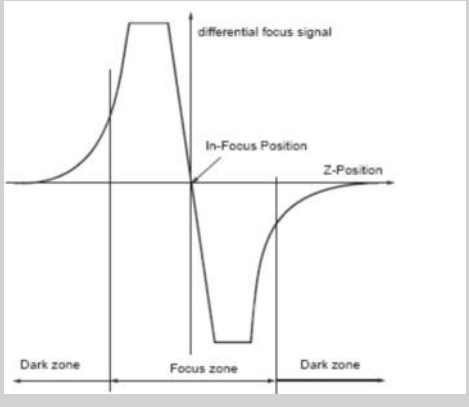
Autofocus routines stored in the firmware allow a function to be implemented which regulates according to an external sensor signal – on the signal output of a vision system, for example. The underlying zero transition method regulates towards a voltage of 0 V at the analog input of the digital controller. This must be able to perform the autofocus routine and have an analog control input.

The autofocus algorithms are possible as standard functions for the E-753 (1 channel), E-725 (3 channels) and E-712 (up to 6 channels) nanopositioning controllers.

ID-Chip Recognition for Automatic Adaptation of the Controllers to the Piezomechanics

The best results for the positional accuracy (linearity) of the piezo system are achieved by adapting various operating parameters. These depend on the individual stage. If digital electronics are tuned once, these parameters are stored in the ID-Chip of the stage. They are therefore automatically available again for the operation at a different digital controller, without the need for an adaptation. This exchangeability between stage and controller is a significant step forward for the flexible use of the systems.

ID-Chip recognition is performed in all E-753, E-725 and E-712 nanopositioning controllers.



Autofocus with the zero transition method: If the control signal is zero, the position is stably maintained. Possible drifts, which lead to a change of the input signal, can be compensated in this way.

DDL: Dynamic Digital Linearization

Nanometer Trajectory during Dynamc Scans

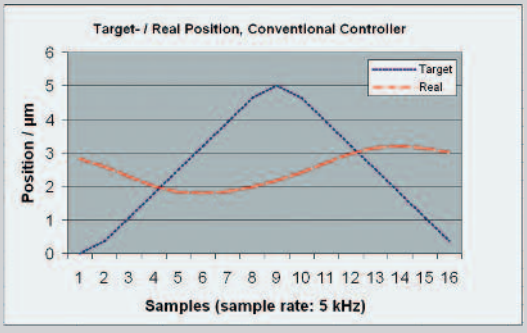
Improved Piezo Control: Dynamic Digital Linearization (DDL)

Conventional piezo controllers cannot completely avoid phase-shift and tracking errors in applications with rapid, periodic motion. This is due in part to the non-linear nature of the piezoelectric material, the finite control bandwidth and the inherent limitations of P-I (proportional-integral) servo-control, which only reacts when a position error is detected. The DDL option (ordering number E-710.SCN), available with recent digital piezo controllers such as E-753 (single-channel, see p. 2-108) or E-712 (multi-channel, see p. 2-140), solves this problem. This technology, developed by PI, reduces the error between the current and desired position to imperceptible values. The dynamic linearity and effectively usable bandwidth are thus improved by up to three orders of magnitude. DDL is of benefit to single- and multi-axis applications where motion follows a given trajectory repeatedly (see measurement curves).

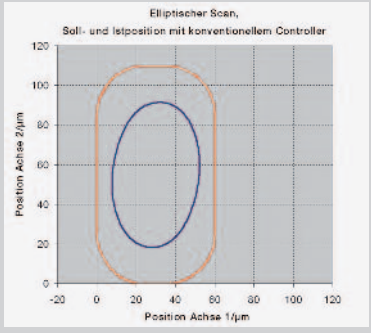
Ordering Information

E-710.SCN
Firmware Upgrade DDL
(Dynamic Digital Linearization)

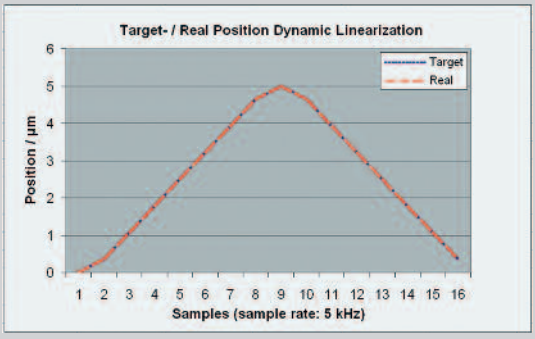
Available for controller E-712, E-725 and E-753.



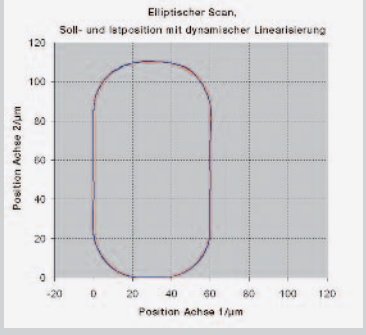
Nanopositioning systems with conventional PID controller: Single axis movement with a 312 Hz triangular signal. The difference between target and actual position can be up to 2.6 µm.



Elliptical scan with a XY piezo scanner and conventional P-I-servo controller. The outer curve shows the desired position, the inner curve shows the actual motion.



Nanopositioning system with DDL option: The same single axis movement as above, with 312 Hz triangular signal. The difference between target and actual position is practically unobservable and is about 7 nanometers.



The same scan as before but with a DDL controller. The tracking error is reduced to a few nanometers, desired and actual position cannot be distinguished in the graph.

DDL: Dynamic Digital Linearization

Application Examples

Moving samples into the spotlight:

Nanopositioning systems in fluorescence microscopy

Single molecule analysis provides detailed information on chemical characteristics or biological functions, but the detection of individual molecules is by no means easy. The extremely sensitive method of laser-based fluorescence analysis is thus used to increase the signal-to-noise ratio.

Confocal microscope with single molecule sensitivity

PicoQuant of Berlin, Germany supplies the MicroTime 200 confocal, time-resolved fluorescence microscope for this task. "This system uses the time-correlated single photon count for its data acquisition and can produce both 2D and 3D images" explains Dr. Felix Koberling, Head of System Development at PicoQuant. This makes it possible to realize a variety of the methods currently used in fluorescence microscopy such as FCS (Fluorescence Correlation Spectroscopy) and FRET (Fluorescence Resonance Energy Transfer) as well as so-called fluorescence lifetime imaging. Here not only the measured intensity but also the respective fluorescence lifetime is used for the visualization and quantification in order to analyze intracellular processes even in living cells. Its modular design means the fluorescence microscope is also very flexible in adjusting to different applications. (www.picoquant.de)

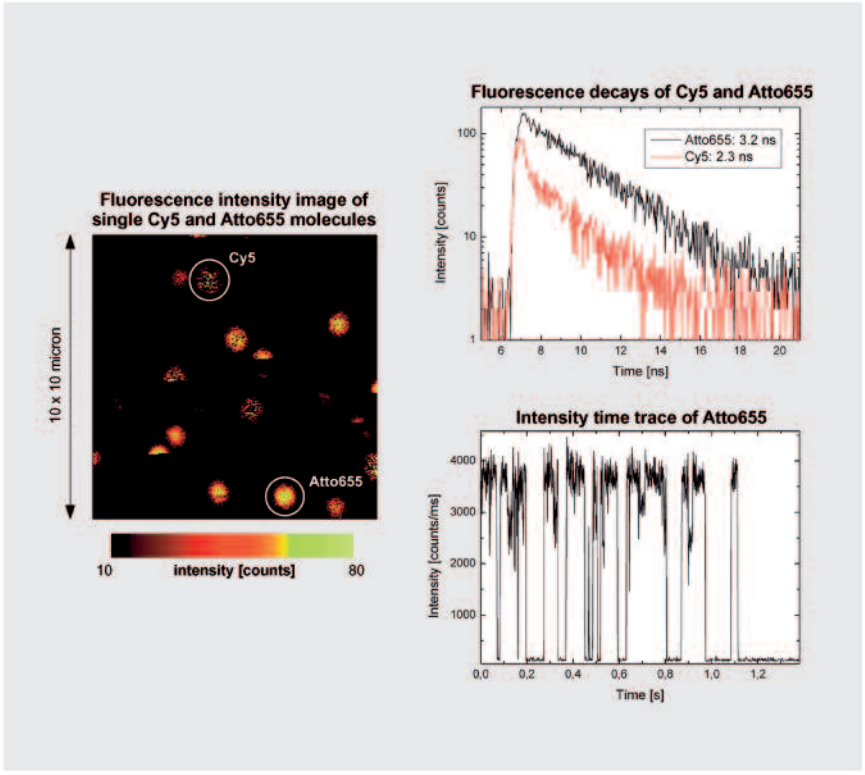
Maximum repeatability thanks to dynamic digital linearization

The P-733.2CD piezo stage was the scanner system of choice for the microscope. With a travel range of 100 x 100 µm and sub-nanometer resolution, this high-accuracy nanopositioning system matches the requirements of fluorescence microscopy perfectly.

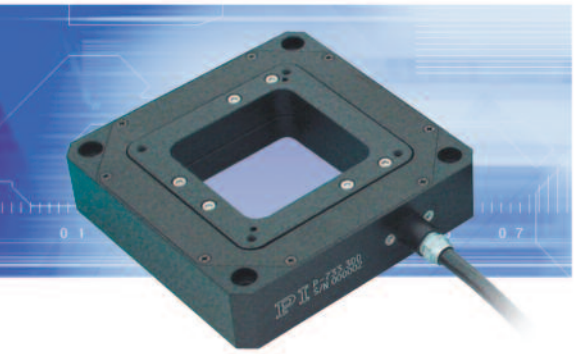
If the sample cannot be moved because it is enclosed in an environmental chamber, for example, the same positioning system can be used to the microscope objective instead. In all cases, however, the integrated direct-measuring capacitive sensors allow the scanner to produce an accurate determination of the actual position value. The first step is typically to record the image of a sample by scanning an area quickly before in a second step individual points of interest are analyzed in detail. In order to return to the exact location of these points within a few nanometers, an advanced digital control algorithm (DDL) was devised. The Dynamic Digital Linearization algorithm improves scanning linearity, i.e. repeatability by up to three orders of magnitude compared to conventional PID (proportional, integral, derivative control).

The third dimension: Additional focus adjustment

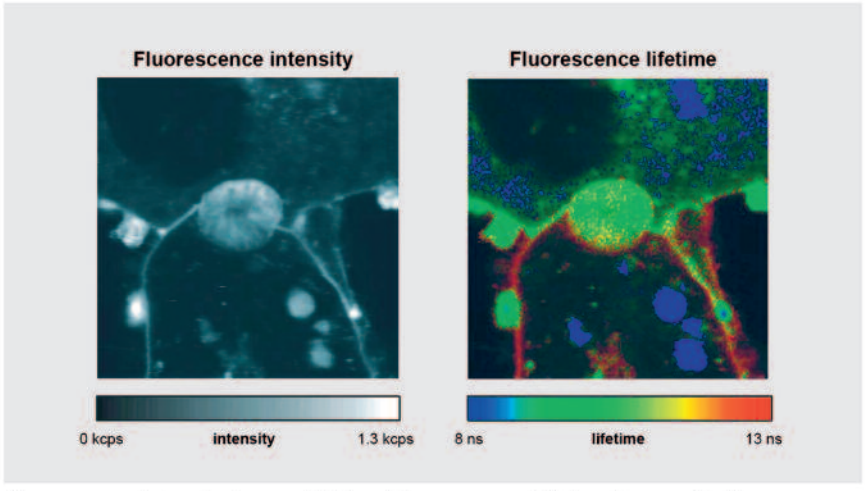
The P-721.CLQ PIFOC® Z-drives are used for three-dimensional images. They provide millisecond response times and their flexure guiding and capacitive sensors enable very accurate positioning, even when the travel ranges are relatively large. "PI's piezo-based nanopositioning systems make a decisive contribution to the fact that we can achieve very high-quality results with our MicroTime 200", says Koberling in conclusion.



Single molecule image of a mixture of immobilized Atto665- and Cy5-molecules. The single molecules can be distinguished by the fluorescence lifetime. (Photo: PicoQuant)



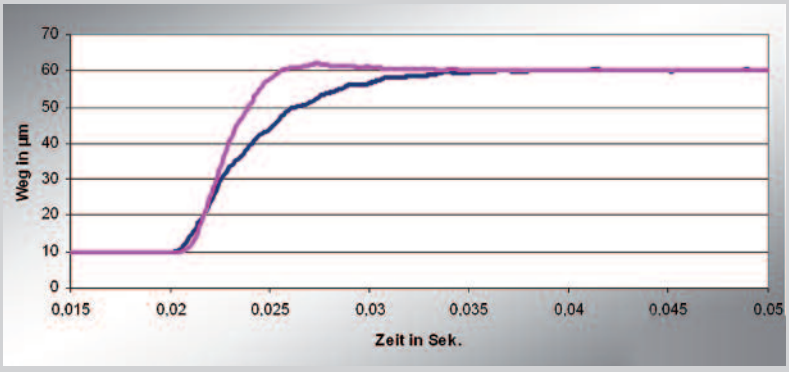
The P-733 piezo-based nanopositioning system provides a travel range of 100 x 100 µm. The optional Dynamic Digital Linearisation (DDL) features for digital motion controllers improves the scanning linearity by a factor of to 1000. Tracking error and phase lag are reduced to almost non noticeable values. (Photo: Physik Instrumente (PI))



Fluorescence intensity image (left) and fluorescence lifetime image of a liver cancer cell, stained with the NBD dye to analyze the organization of lipids. In the image on the right, the lifetime can be used to clearly identify different lipid structures. (Photo: PicoQuant)

Advanced Piezo Control

Alternative Regulation Concept for Faster Settling



Transient response of an system with optimated PID parameters (blue) and Advanced Piezo Control (pink).

An alternative control concept is provided for the modular E-712 controller for nanopositioning systems: Advanced Piezo Control. It is based on a state controller which, in turn, is based on a model of the positioning system.

Advanced Piezo Control actively damps the resonance frequency, in contrast to conventional PID controllers with notch filter where the mechanical resonance is cut out of the excitation spectrum.

Advanced Piezo Control for Faster and More Stable Control

The consequences are faster settling times and lower sensitivity with respect to interferences from the outside.

The phase trueness is significantly improved compared to the damping with one or even two notch filters. This has immediate effects on the trajectory trueness and the settling response.

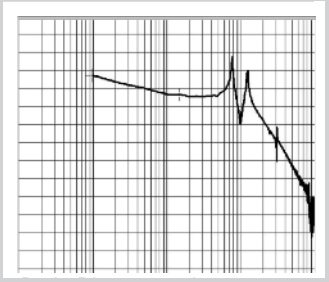
Limitations of the Advanced Piezo Control

If the mechanical system has too many resonances close together, or if the resonance frequency to be damped is about 1 kHz or more, the state controller in this form no longer has any advantage over conventional PID controllers. Please discuss your application with us.

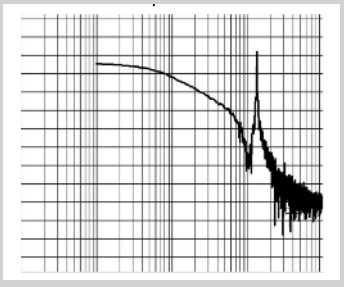
Ordering Information

E-712.U1
Firmware Upgrade Advanced Piezo Control Regleroption

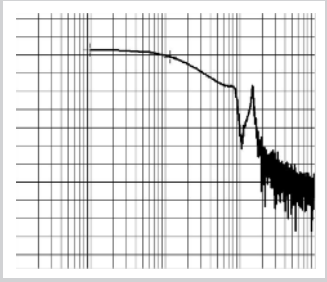
Advanced Piezo Control is also available for the Controller E-753 (1 Channel) and for the E-725 (3 Channels). Ask your PI Sales Department.



Bode diagram of an unloaded, unregulated system with two resonance frequencies.



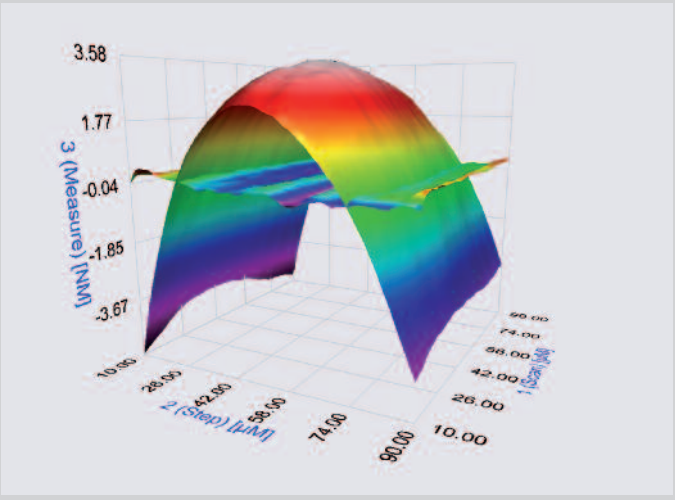
Bode diagram of a regulated system with one notch filter at the first resonance.



Bode diagram of a system regulated with Advanced Piezo Control. The resonances are better suppressed, the phase deviation is lower compared to the suppression with a notch filter.

PICOPlane™ for Piezo Systems

Implement Motions with Nanometer Flatness



The PicoPlane™ algorithm reduces the undesirable crosstalk on the Z-axis to values below one nanometer

PI nanopositioning systems intrinsically have a high tracking accuracy, which is typically in the region of about 10 nanometers.

This is achieved by using flexures which are very stiff in the direction perpendicular to the direction of motion.

AFM—One Nanometer is Just About Good Enough

There are applications, however, which require a planar motion of one nanometer or so. This is the case with scanning atomic force microscopes, where the structure of the sample is on the atomic scale and where inaccuracies in the sample positioning cannot be tolerated.

PICOPlane™ for Nanometer Evenness

PICOPlane™ is a one or two-dimensional method which counteracts the crosstalk into the axis perpendicular to the scan plane or the line of motion and reduces it to a minimum.

The requirement here is a dynamic and finely controllable axis with small stroke. This axis operates in the direction of the crosstalk, which has previously been measured and stored in the controller. The mapping process here has the advantage over the active control that the correction movement can occur virtually in real time. This ensures that, during the scanning motions, no phase shift between the actual and controlled crosstalk occurs as distortion.

Hardware Requirements

This additional axis can either be added to the existing piezo system, or is already integrated. PI offers both solutions, depending on the nanopositioning system. The digital controller belonging to the system must provide an additional unregulated channel and support the PICOPlane™ algorithm.

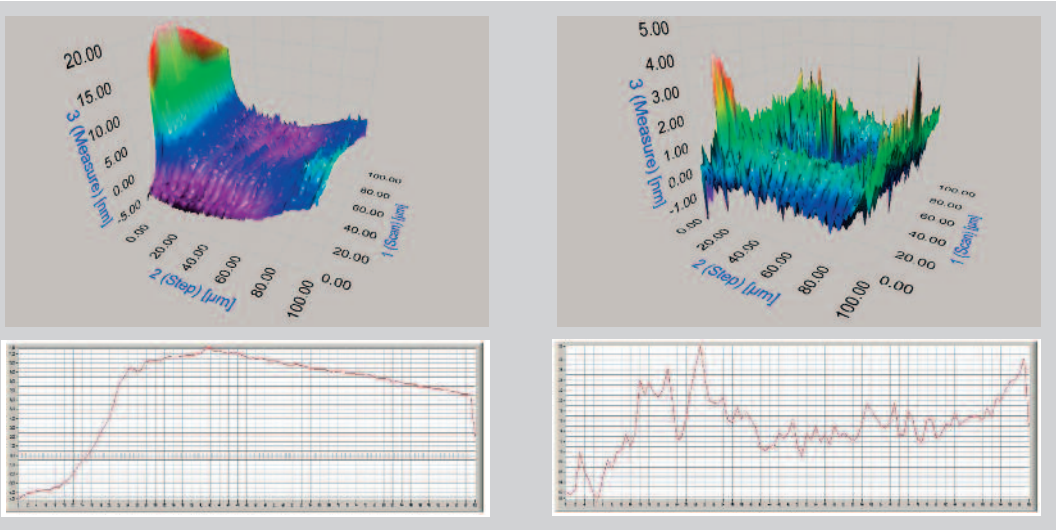
Ordering Information

E-712.U2
Firmware Upgrade PicoPlane™: Option for Nanometer Guiding Accuracy (compatible hardware required)

PICOPlane™ requires additional Amplifier Channel and a PICOPlane™ Axis.

PICOPlane™ is also available for Compact gerät E-725 (3 Channels).

PIHera™ XY-scanner with travel range of 800x800 µm and PICOPlane™ Upgrade



Area scan and cross section of the measurement of the crosstalk from the XY plane without (left) and with (right) PICOPlane™ activated. The effect is a significantly reduced deviation in the Z-axis.

E-861 PiezoWalk® NEXACT® Controller/Driver

Networkable Controller for NEXACT® Linear Drives and Positioners

PiezoWalk® System: E-861.1A1 NEXACT® Controller with open-loop N-310.01 NEXACT® linear drive; suitable for installation in stage with linear encoder

Ordering Information

E-861.1A1
NEXACT® Controller, 1 Channel, Linear Encoder

- **For NEXACT® Drives and Positioning Systems**
- **Complete System with Controller, Integrated Power Amplifiers and Software**
- **Open-Loop Operation, or Closed-Loop with Linear Encoder**
- **High Performance at Low Cost**
- **Daisy-Chain Networking for Multi-Axis Operation**
- **Non-Volatile Macro Storage for Stand-Alone Functionality with Autostart Macro**
- **I/O for Automation, Joystick for Manual Operation**
- **Parameter Changes On-the-Fly**

Technical Data

Model	**E-861.1A1**
Function	Controller for NEXACT® drives / systems
Drive type	N-310.01 NEXACT® linear drive
Channels	1
Motion and control	
Servo characteristics	P-I-D servo control, parameter change on-the-fly
Trajectory profile modes	Trapezoidal
Encoder input	Analog encoder input sine-cosine, interpolation circuit preset for differential transmission, 2 V_{pp} amplitude and 2.27 V offset of the encoder signal
Stall detection	Servo off, triggered by programmable position error
Input limit switch	2 x TTL (pull-up/pull-down, programmable)
Input reference switch	1 x TTL
Electrical properties	
Output power	max. 40 W
Output voltage	-10 to +45 V
Current consumption	max. 2 A
Interfaces and operation	
Communication interfaces	USB 1.0, RS-232 (9-pin (m) D-Sub)
Motor connector	D-Sub 15-pin (f) High Density
Sensor connector	D-Sub 15-pin (m) High Density
Controller network	Up to 16 units on single interface
I/O ports	4 analog/digital in, 4 digital out (TTL)
Command set	PI General Command Set (GCS)
User software	PIMikroMove™, PI Terminal
Software drivers	GCS-DLL, LabVIEW drivers
Supported functionality	Start-up macro; data recorder for categories like current position or velocity; internal safety circuitry: watchdog timer
Manual control (optional)	Joystick, Y-cable for 2D motion, pushbutton box
Miscellaneous	
Operating voltage	24 V included: external power supply, 24 V, 2.5 A
Operating temperature range	0 to +50 °C
Mass	1.1 kg
Dimensions	206 x 130 x 66 mm (with mounting rails)

C-663/863/867 Mercury™Motion Controller

Networkable single-axis controller for step, DC and piezo motors

The C-867 piezomotor controller and the M-692 low-profile positioner with integrated PILine® ceramic linear drive

- **Flexible and reasonably priced**
- **Stepper motor control or servo controller for DC and piezo ultrasonic motors**
- **High-speed encoder input up to 50 MHz**
- **USB, RS-232 and analog interfaces**
- **4 + 4 programmable TTL inputs/outputs for flexible automation**
- **Macro programmable for stand-alone operation**
- **Daisy-chain network capability for up to 16 axes**
- **Nonvolatile EEPROM for macros and parameters**
- **Optional joystick for manual operation**

Technical Data

Model	C-863.10	C-663.10	C-867.160
Function	DC-servo-motor controller	Stepper motor controller	Controller / driver for PILine® piezo motors / systems
Drive configuration	DC motor analog and PWM (ActiveDrive™)	2-Phase-Stepper motor	PILine® motors, single or dual U-161 to U-164
Motion and control			
Servo characteristics	P-I-D-servo control, parameter change on-the-fly	–	P-I-D-servo control, parameter change on-the-fly
Trajectory profile modes	Trapezoidal, point-to-point	Trapezoidal, point-to-point	Trapezoidal, point-to-point
Encoder input	A/B quadrature TTL signal; 20 MHz	–	A/B quadrature TTL signal; 50 MHz
Micro-step resolution	–	1/16 full step	–
Stall detection	Servo off, triggered by programmable position error	1/16 full step	Servo off, triggered by programmable position error
Input limit switch	2 x TTL, programmable	2 x TTL, programmable	2 x TTL, programmable
Input reference switch	1 x TTL, programmable	1 x TTL, programmable	1 x TTL, programmable
Motor brake	1 x TTL, software controlled	1 x TTL, programmable	–
Electrical properties			
Output power	max. 30 W (PWM)	15 to 30 V	max. 15 W
Output voltage	0 to 15 V	–	max. 200 Vpp
Current limiting / motor phase	–	1000 mA	–
Interfaces and operating			
Communication interfaces	USB, RS-232	USB, RS-232	USB, RS-232
Motor connector	Sub-D connector, 15-pin (f)	Sub-D connector, 15-pin (f)	MDR14
Controller network	Up to 16 units on single interface	Up to 16 units on single interface	Up to 16 units on single interface
I/O ports	4 analog/digital Inputs, 4 digital Outputs (TTL)	4 analog/digital Inputs, 4 digital Outputs (TTL)	4 analog/digital Inputs, 4 digital Outputs (TTL)
Command set	Mercury™ Command Set, GCS (via DLL)	Mercury™ Command Set, GCS (via DLL)	PI General Command Set (GCS)
User software	PIMikroMove®, MMCRun	PIMikroMove®, MMCRun	PIMikroMove®
Software drivers	GCS (PI General Command Set)-DLL, LabVIEW drivers, native Mercury™ DLL	GCS (PI General Command Set)-DLL, LabVIEW-drivers, native Mercury™ DLL	GCS (PI General Command Set)-DLL, LabVIEW drivers
Supported functionality	Start-up macro; internal safety circuitry: Watchdog Timer	Start-Up Macro	Start-Up Macro, Macro, data recorder for recording parameters as motor input voltage, velocity position or position error
Manual control (optional)	Pushbutton box, joystick (for 2 axis), Y-cable for 2D motion	Pushbutton box, joystick (for 2 axis), Y-cable for 2D motion	Pushbutton box, joystick (for 2 axis), Y-cable for 2D motion
Miscellaneous			
Operating voltage	15 to 30 V included: external power suplly 15 V / 2 A	24 VDC from external power supply (included)	24 VDC from external power supply (included)
Operating temperature range	0 to +50 °C	0 to 50 °C	+5 to +40 °C
Mass	0.3 kg	0.3 kg	1.01 kg
Dimensions	130 x 76 x 40 mm	130 x 76 x 40 mm³	206 x 130 x 66 mm (without mounting rails)

Ordering Information

C-867.160
Piezomotor Controller with Drive Electronics, Networkable, for PILine® Systems

C-663.10
Mercury™ Step Stepper Motor Controller, 1 Channel, with Wide-Range Power Supply (24 V)

C-819.20
2-Axis Analog Joystick for Mercury™ Controller

C-819.20Y
Y-Cable for Connecting 2 Controllers to C-819.20

C-170.IO
I/O Cable, 2 m, Open End

C-170.PB
Push Button Box, 4 Buttons and 4 LEDs

Hexapod Controller

Easily Operate Powerful Multi-Axis Positioning

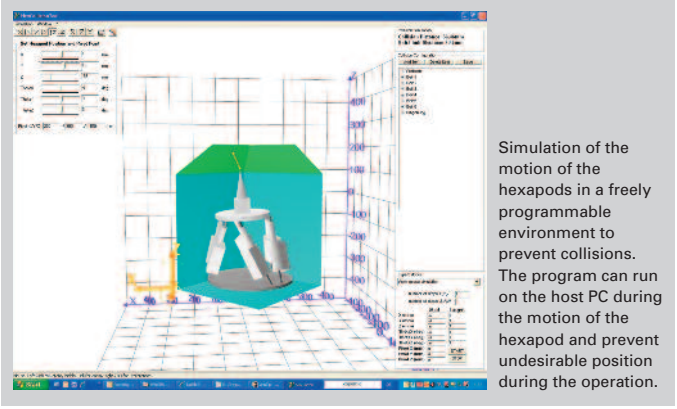
High-Power Hexapod Controller

- **For hexapods plus two further motorized axes, six further piezo axes as optional extra**
- **Real-time operating system**
- **TCP/IP and RS-232 interface**
- **Simple placing of commands in Cartesian coordinates, integrated coordinate transformation**
- **PivotAnywhere™: Freely programmable pivoting point of the motion**
- **Comprehensive software package**

Technical Data

Function	Multi-Axis Automation platfrom; Hexapod controller
Drive type	Servo motors and piezo drives (optional)
Channels	Up to 8 axes, (servo motors), max. 6 piezo axes (optional)
Motion and control	
Servo characteristics	Programmable 32-bit-PID V-ff filter, 100 µs/active axis
Processor	CPU 133 MHz C-842.23/C-842.43: Motion chip, 2.5 kHz Servo Update Rate
Electrical properties	
Operating Voltage	100 to 250 VAC, 50 / 60 Hz
Output power per channel	Analog H-bridge ±12 V, 5 W/channel, 12-bit D/A-converters, 10-bit Output for PWM drivers, 24,5 kHz
Output voltage per channel	±10.5 V analog PWM: TTL for SIGN and MAGN
Current limitation	1 A max. (short-circuit-proof)
Interfaces and operation	
Communication interfaces	RS-232, TCP/IP
Motor connector	System connector
Controller network	Via TCP/IP
Command set	PI General Command Set (GCS), ASCII Communication
User software	PIMikroMove®
Software driver	GCS-DLL, LabVIEW drivers
Supported functionality	Autostart Macro, user-programmable macros, monitor and keyboard connectors, motor-brake control, switching of high-power relays, Read-out of analog interface boards (photometer cards)
Manual control	with front keyboard and LCD-display (optional) Manual control F-206.MC6 (optional)
Miscellaneous	
Operating temperature range	+10 °C to +50 °C
Dimensions	19-inch case, 450 mm x 460 mm x 180 mm


M-850 Precise Hexapod for Loads up to 200 kg with Standard Controller


Simulation of the motion of the hexapods in a freely programmable environment to prevent collisions. The program can run on the host PC during the motion of the hexapod and prevent undesirable position during the operation.

Thinking in Systems

All in One Hand – All from One Hand

Drive, sensors, mechanics and control electronics with software – components of PI's positioning systems

To assure that the subassemblies used satisfy PI's quality requirements, PI fabricates all components itself, develops the ultra-high-resolution sensors and controllers, and programs both control algorithms and operating software. In Lederhose (Thuringia) at PI Ceramic, piezoelectric drives are developed, optimized and manufactured. With PIC, PI is the only positioning system manufacturer worldwide which develops its own piezoelectric actuators to meet market requirements. The resulting flexibility is an important reason for the technological leadership enjoyed by PI and its customers.

Capacitive Sensors for Nanometrology

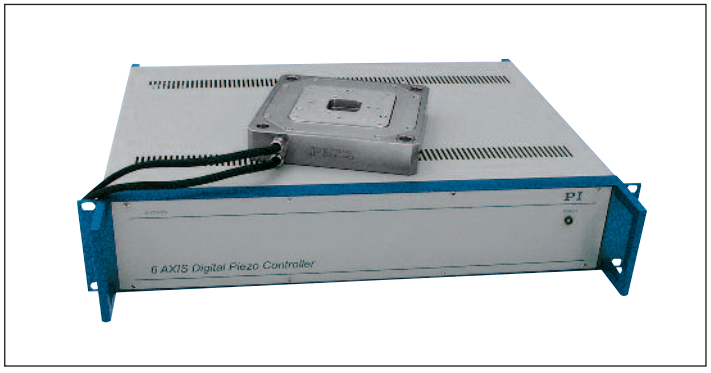
Special sensors can fulfill the requirements of many applications for dynamics, linearity and stability better than that provided by standard strain gauges. Non-contact capacitive sensors measure position without drift and provide linearity to 0,01% of the measurement range. The high resolution of up to 0.0005% allows detection and compensation of the smallest position errors. PI uses capacitive sensors developed in-house, making it possible to adapt the sensor geometries to the space available. Placing the sensors as close as possible to the moving platform, PI provides direct metrology systems—systems in which motion is detected where it is used. PI capacitive sensors are also offered as stand-alone products for nanometrology applications.

Control of Positioning Systems

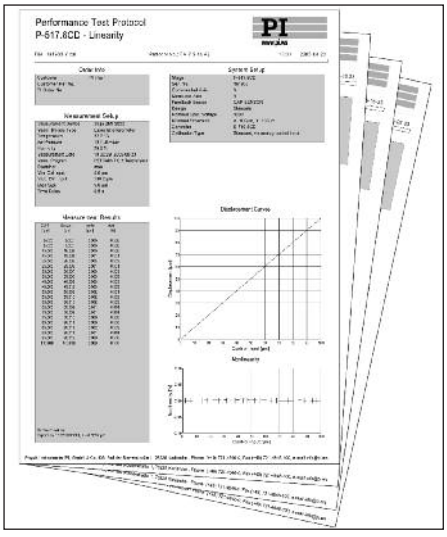
The characteristics of drives and sensors are made usable by the drive and control electronics. PI has designed all electronics to match the mechanics optimally. Electronic amplifiers for piezoelectric actuators must provide low noise and drift. Fast rise times make possible sub-millisecond response times and optimized control algorithms minimize settling times. Digital controllers include advanced algorithms to improve the system performance: coordinate transformation matrices matched to the mechanical geometries allow for commanding complex systems in Cartesian coordinates; filters support servo-control by suppressing resonant vibrations; pre-shaping of control signals minimizes trajectory deviation during dynamic scans. All functions are easily accessible through fast and modern interfaces and comprehensive user software and software drivers.

Flexibility Through Competent Partners

High quality requires qualified partners. Over the years PI has thus qualified a number of highly specialized suppliers with whom we now work as partners—partners whose conception of quality is every bit as high as our own.



E-710 6-axis Digital Piezo Controller with 6-DOF piezo nanopositioning stage



All PI nanopositioning systems come with extensive system performance documentation

PI Software

Operating Positioning Systems Effectively & Conveniently

Communication between PI components is based upon a universal command set (GCS – General Command Set). It decouples hardware and software, and is used for all drive principles.

The high quality of positioning systems is made apparent in daily operation by PI software. Starting with simple commissioning, through convenient operation with a graphical interface, to quick and simple integration in customized programs with high performance, PI software covers all aspects important to an application.

Universal Command Set Simplifies Commissioning and Programming

For uniform operation of nano and micropositioning systems, the universal PI General Command Set (GCS) is used. GCS operation is independent of the controller or drive principle used, so that several positioning systems can be controlled together, or new systems can be introduced with a minimum of programming effort. With GCS the development of custom application programs is simplified and less prone to errors, because the commands for all supported devices are identical in syntax and function. Through the use of the GCS command set with its convenient functions, the orientation phase and application development process is significantly accelerated.

The GCS commands are available at the controller terminal, in macros and in the form of a universal driver set for LabVIEW (VIs), Windows dynamic link libraries (DLL) and Linux libraries for 32- and 64-bit platforms. This facilitates the development of custom macros, as well as integration with programming languages like LabVIEW, C++ or MATLAB.

All about software in the internet—a server offers download of manuals and software CD mirrors

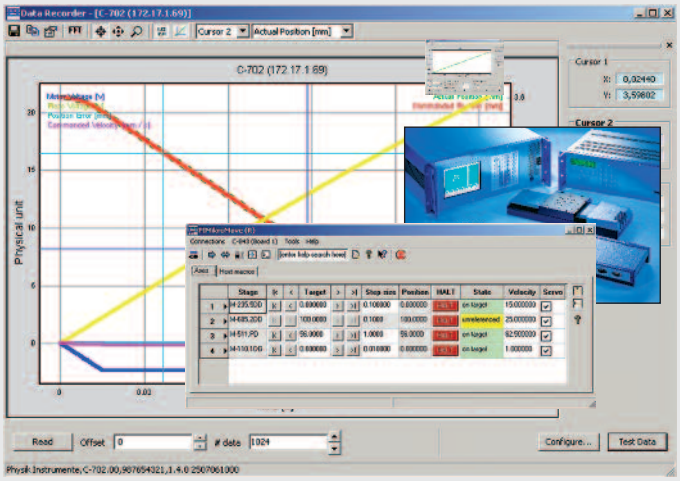
Software Updates Online

PI supports users with free updates, detailed online help and well structured manuals which ease initiation of the inexperienced but still answer the detailed questions of the professional.

Supported Operating Systems
Microsoft Windows Vista
Microsoft Windows XP
Microsoft Windows 2000
Linux

PIMikroMove™ Software

Simple Operation of Positioning Systems



A uniform interface for all axes

- **Operation of PI Motor, Piezo, Piezomotor, Hexapod & Hybrid Controllers**
- **1D/2D Scan and AutoFind**
- **Macros for Recurring Tasks and Automation**
- **Optimizing all Servo Parameters**

PI positioning systems can be controlled with PIMikroMove™ in a clear and simple manner; all connected controllers and axes are accessed via the same graphical interface.

PIMikroMove™ supports quick commissioning of controllers and positioners, comprehensive system optimization as well as the programming of macros.

All Axes in One View

With PIMikroMove™ all axes connected can be controlled from one program instance. This, independent of which PI controller is connected to which axis and which interface (TCP/IP, USB, RS-232, GPIB, PCI). For example, it is possible to have two axes in an XY application connected to two different controllers, but still command them with PIMikroMove™ from the same window.

Optimal System Behavior

PIMikroMove™ also allows the user to optimize the system behavior through convenient servo tuning. This possibility is especially helpful if the mechanical properties of a system are changed, for example by applying a different load. The system response and stability can then be optimized with the convenient parameter tuning tool. For recurring tasks, different sets of optimized parameters can be saved as stage profiles and then activated as needed in custom-programmed applications.

Macros Ease Recurring Tasks

PIMikroMove™ considerably simplifies the creation of macros for recurring tasks. Execution of a macro, consisting of a previously stored list of GCS commands, can be commanded over the interface or, if supported by the controller, run automatically on power-up, with or without a host PC connected.

Controllers without their own macro facility, like the C-843, can be commanded by host macros which PIMikroMove™ edits and stores in the host PC. Host macro execution can be triggered with digital I/O lines or software commands and support multiple axes connected to different controllers.

With the position pad, two or more independent axes can be moved by a mouse or joystick as an XY stage, also in vector moves.

1D/2DScan and AutoFind

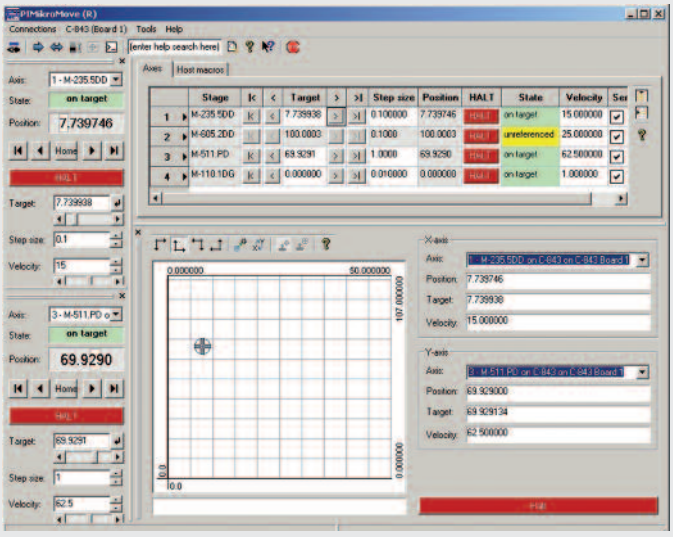
Scan 1D/2D can measure an input source while moving up to two axes. Moved axes and input source need not be assigned to the same controller. The input source to be measured can be an analog input, an axis position or a raw position sensor value. The measured data is visualized and can be saved to a file on the host PC. AutoFind tries to find the maximum of an intensity signal by modifying the position of two axes.

FFT, Profile Generator, Data Recorder

PIMikroMove™ also supports controller-specific features.

Data recorder: record various motion and system parameters, run FFT (Fast Fourier Transformation) on the data as well as export it to programs like Microsoft Excel (CSV format).

Profile Generator: synchronize motion of several axes along multi-order, mathematically defined curves or customized arbitrary functions.



All axes and the position pad can be displayed in one window

Moving the Nanoworld

NanoAutomation®: Precision Positioning for Science and Industry

PI headquarters in Karlsruhe

Future Technology Solutions

Today PI delivers micro- and nanopositioning solutions for all important high-tech markets:

- Semiconductor Technology
- Optical Metrology, Microscopy
- Biotechnology and Medical Devices
- Precision Automation and Handling
- Precision Machining
- Data Storage
- Photonics, Fiber Optics, Telecom
- Nano Technology
- Microsystems Technology
- Aerospace Engineering
- Astronomy


PI reception desk: Our employees look forward to your visit

PI is market and technological leader for precision positioning systems with accuracies well under one nanometer. Nanometer-range motion control is the key to worlds where millions of transistors fit on one square millimeter, where molecules are manipulated, where thousands of "virtual slices" are made in the observation of living cells, or where optical fiber bundles no larger than a human hair are aligned in six degrees of freedom.

Worlds We Call NanoWorlds

Continuous innovation and reinvestment of profits over the decades has allowed PI to attain its present market status. This status is also based on long-term customer relationships and on the freedom to transform ideas into reality.

Over 30 Years Experience

When PI introduced piezoelectric nanopositioning technology more than 30 years ago, typical customers were research labs and universities working on laser cavity tuning, Fabry-Perot interferometers and filters. Few foresaw that whole industrial sectors like semiconductor manufacturing or biotechnology would become dependent on progress in nanopositioning. Today, not even the precision machining industry can do without nanometer-level positioning systems.

Key Technologies In-House

PI follows a vertical integration strategy designed to develop and maintain all key technologies in-house. We supervise each and every step from design to delivery in the following areas: software, precision mechanics, digital and analog control electronics, sub-nanometer capacitive position sensors, piezo ceramics and piezo actuators. This assures the highest quality and reduces cost.

The PI-Group

High Quality and Strong Brands on a Global Scale

PI Ceramic—a PI Subsidiary—is a world-class supplier of high-performance piezoelectric actuator and transducer components and subassemblies.

PI—World Market Player

As a privately run company with a healthy growth rate, over 500 employees and a flexible, vertically integrated organization, PI can meet the most diverse requirements in the area of innovative precision positioning and supply customers anywhere in the world with outstanding products.

International Service and Sales Network

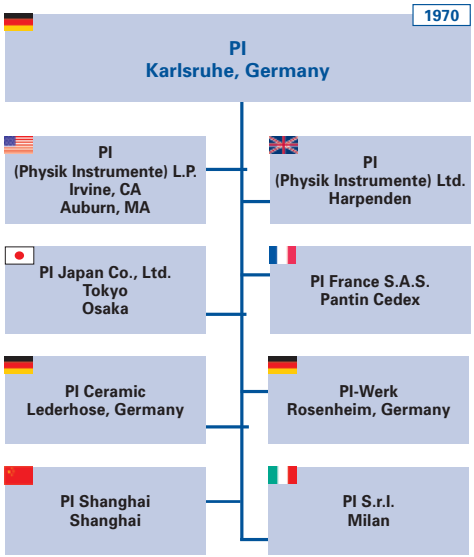
PI has established subsidiaries for sales and service in the most important local markets all over the world and maintains nanometrology test labs on three continents. In addition to PI's main R&D and manufacturing centers in Europe, PI Shanghai and PI USA provide development and manufacturing capabilities to meet the specific demands of local markets faster. In addition to the branch offices, PI has distributors in many other industrial countries. A network of highly qualified personnel around the world assures successful, long-term relationships with customers.

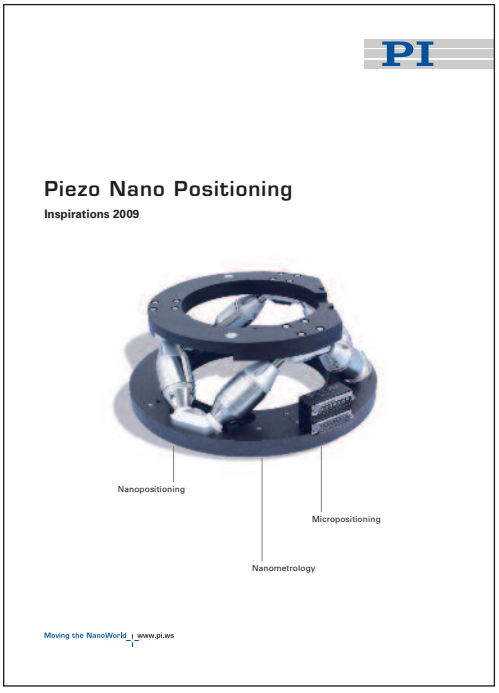
Quality and Brand Policy

We measure the quality and reliability of our products against the strictest of standards. ISO 9001 certification, which also emphasizes points like customer expectations and satisfaction, has been accorded in 1994, making PI the first manufacturer of nanopositioning technology following this standard. PI's Integrated Management System (IMS) includes also Environmental Protection and Job Safety (according to ISO 14001:2004 and OHSAS 18001:1999). This system assures legal conformity of all procedures as well as continuous optimization of the processes at all PI locations.

PI brands and colors are well known throughout the high-tech world. PIFOC® is almost used as a synonym for objective positioners in general and PICMA® stands for the highest reliability in piezo actuator products.

PI stands for quality and precision – worldwide.





The new hardbound "Piezo Nano Positioning Inspirations 2009" catalog from PI is available now. The 530 page publication is the most comprehensive reference book on the fundamentals of nanopositioning, piezo systems and micropositioning technology yet. The new catalog contains 200+ product families – 30% of them new – with more than 1000 drawings, graphs, images and technical diagrams.

The 530 page publication presents PI's state-of-the-art products and technologies-such as:
Nanopositioning / Scanning Stages
Scanning Microscopy Stages
Steering Mirrors, Mirror Shifters
Piezo Actuators
Piezo Motors
Piezo Controllers
Motorized Stages & Actuators
Motor Controllers
Hexapod 6-Axis Alignment Systems

The catalog also contains a tutorial on piezo technology and application examples of nanopositioning products in the following industries:
Biotechnology / Life Sciences
Semiconductor Technology
Data Storage Technology
Nanotechnology
Aeronautics
Astronomy
Adaptive Optics
Metrology / Laser-Systems
Precision Machining

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