Capacitance-Based

Pressure Transducer Handbook

Understanding, specifying and applying *Capacitive Pressure Transducers*

Useful information for every design engineer

TECHNICAL DATA

The sensing and measurement of physical quantities through small changes in electrical capacitance is scarcely a new concept. The natural benefits of this approach were recognized for many years. But it was not until Setra engineers introduced new materials, new designs, and innovative, dedicated circuitry that the technique's full potential was realized in the practical, real world of pressure measurement.

Today, capacitive pressure transducers are widely used in both highly-specialized and general equipment applications that call for thoroughly dependable accuracy and/or long-term stability. They are especially in demand wherever a job involves adverse operating conditions, such as shock, vibration, temperature extremes, etc. Designers and engineers find that the electrical simplicity and inherently rugged mechanical structure of the typical capacitive sensor result in relative freedom from the problems to which more glamorous techniques are usually susceptible.

The specific facts and data on the following pages will help to introduce you to capacitive pressure transducers (if you are not already familiar with them), and will assist you in evaluating their applicability to pressure measurement problems that call for more than offhand solutions.

C O N T E N T S

An Introduction to Capacitance Based Pressure Transducers

Equipment designers today can choose from an impressive array of commercially available pressure transducers. Sensing devices range from modern versions of the venerable manometer and Bourdon tube, through bonded strain gauges to sophisticated units using, deposited or ion-implanted piezoresistive semiconductor elements on silicon or sapphire substrates.

And the list goes on, to include such special-purpose types such as LVDT, variable reluctance, Hall effect, inductive and potentiometric devices.

Although most of these transducers perform acceptably in specific applications, virtually all have inherent operating and performance limitations. Selection of a particular transducer type is usually a trade-off in which certain acknowledged disadvantages are tolerated in order to achieve a desired result. Lower cost, for example, is often bought at the expense of long-term stability...or accuracy...or reliability.

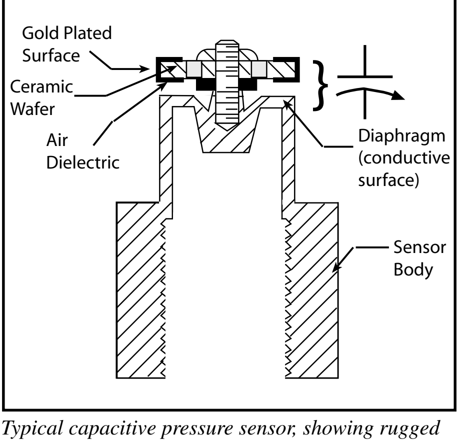
In this somewhat overcrowded pressure transducers field, **Setra capacitive devices** stand out as perhaps the closest thing to a universal pressure transducer style. They have generally broader application, greater overall reliability and physical ruggedness, and in most cases, require fewer trade-offs than other types. Costs, while often thought to be higher, are actually extremely competitive in quantity.

Capacitive Transducers...

functional simplicity/ structural sophistication

Setra's capacitive pressure transducers are expertly designed adaptations of a simple, durable and fundamentally stable device...the electrical capacitor.

In a typical Setra configuration, a compact housing contains two closely spaced, parallel, electrically-isolated metallic surfaces, one of which is essentially a diaphragm capable of slight flexing under applied pressure. The diaphragm is constructed of a low-hysteresis material such as 17-4 PH SS or a proprietary compound of fused glass and ceramic (Setraceram™). These firmly



Typical capacitive pressure sensor, showing rugged construction. Materials are carefully selected for compatibility to minimize environmental effects. (Capacitance gap is accentuated for illustration.)

secured surfaces (or plates are mounted so that a slight mechanical flexing of the assembly, caused by a minute change in applied pressure, alters the gap between them (creating, in effect, a variable capacitor).

The resulting change in capacitance is detected by a sensitive linear comparator circuit (employing proprietary, custom-designed ASICs), which amplifies and outputs a proportional, high-level signal.

The inherent simplicity and ruggedness of this physical configuration, the fact that all wettable parts are of stainless steel or low-hysteresis ceramic, and a careful marriage of the mechanical assembly to the electronic circuitry, all combine to create a transducer that exhibits uniformly superior performance and reliability.

Comparative Operating Features

High Accuracies

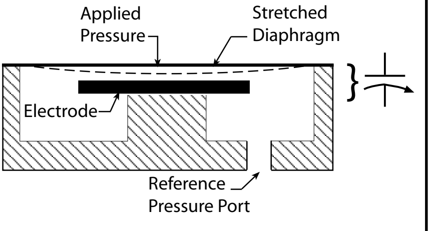
Depending on application requirements, Setra transducers can provide accuracies as high as ±0.02% FS. Such precision, not attainable by many other transducer types, is particularly useful in test-and-measurement applications, barometric standards transfer, altimetry, etc.

Minimal Mechanical Motion

A measurable voltage change is produced by a very slight change in capacitor plate gap. The extremely small deflection of Setra sensor diaphragms helps to minimize hysteresis and repeatability errors and to provide very fast response times.

Broad Range Capabilities

Setra transducers provide an unusually broad selection of pressure ranges. Pressure from 0.05 in. W.C. to 10,000 psig can be measured accurately and consistently.



Cross-section of Setra's Model 239 — a high-accuracy, low differential pressure transducer. Its unique, thermally-stretched diaphragm combines high sensitivity with optimum accuracy (0.14% FS) and thermal characteristics (Operating from 30°F to 150°F with <±1% FS/100°F thermal effect). (Capacitor gap and deflection accentuated for illustration.)

Long Term Stability

All Setra transducers are designed and specified to maintain accuracy settings longer than competitive units. Unlike sensors such as bonded strain gauges, capacitive transducers exhibit extremely low creep, aging effects, humidity effects and other common enemies of output stability. Setra transducers provide long-term zero stabilities as low as 0.05% FS/yr.

Setra
Typical Pressure Transducer Types

Model 204
High Accuracy/Broad Range
Test & Measurement

Model 760
Capacitance manometer
Absolute Pressure transduce
Test & Measurement

Models 206/207
Industrial/OEM

Models 209
Industrial/OEM

Models 270
High Accuracy/Low Medium Pressure
Setraceram — Barometric Use

Models 239
High Accuracy/Low Differental Pres.
HVAC — R&E — Environmental

Models 230 w/3-Valve Manifold
Wet/Wet
Process Control — HVAC — Etc.

Models 230
Wet/Wet
Process Control — HVAC — Etc.

Models 264
Low Differential Pressure
HVAC

Models C-290
Flush Diaphragm/3A Sanitary
Beverage/Dairy/Food Processing

Models 224
Flow-Through
Ultra-High Purity Applications

Models 201
Low Differential Pressure
Industrial

Ultra-Low Pressure Generating and Documenting Calibrator

Micro-Cal Model 869

Datum 2000 Series
Dual-Channel Digital display/Manometer
Bench-top/Panel-mount
reference-Analog display

Models 370 & 470
Environmental Monitoring and
Test and Measurement

High-Level Output

Setra transducers need no signal amplification. As a result, they avoid problems common to low-level output devices, such as piezoresistive (thin film and IC) types. Such problems normally include poor long-term stability, thermal instability, high RFI susceptibility and humidity effects.

Broad Media Compatibility

All wetted parts of Setra sensors are either of stainless steel or tough ceramic material. As a result, they can handle a wide range of difficult fluids, including acids, salt solutions, corrosive gasses and liquids with high particulate content.

High Electromagnetic Compatibility (EMC)

Setra's sturdy metal cases, shielded cables and careful construction, together with the high-level output characteristic of capacitive sensing, ensure high immunity to external radio frequency and electrostatic discharge interference. Similarly, they are essentially immune to radio frequency interferences emissions.

Resistant to Harsh Environments

Setra's transducers are tough! Those models designed for industrial use are specified to withstand a minimum of 10 million full scale cycles with specified accuracy and thermal performance. When they are installer per ANSI B40.2 applying a maximum of 75% F.S. pressure, they will exhibit unlimited cycle life. What's more, all industrial units are certified to between 100 G and 200 G shock loading, and can withstand vibration at minimum peak amplitudes from 10 G to 20 G.

Capacitance-Based Pressure Transducers
SUMMARY OF CHARACTERISTICS

Transducer Characteristic	*In use, this translates to...*
High-Level Output	*Better Accuracy - High Stability* *Lower RFI Vulnerability*
Rugged, Shielded Construction	*Broad Media Compatibility* *High Shock & Vibration Tolerance* *High Electromagnetic Compatibility* *High Resistance to Harsh Conditions*
Proprietary, Linear Circuitry	*Highest Accuracy*
Carefully Selected, Compatible Materials	*Excellent Temperature Stability* *Minimum Humidity Effects*
Minimum Mechanical Motion	*Low Hysteresis - High Repeatability*
Capacitive Sensing	*High Sensitivity -* *Accurate Low-Pressure Sensing*

Comparative Characteristics
Capacitance v. Strain Gauge Sensors

	Strain Gauge Transducers			SETRA Capacitive Transducers
	BONDED	THIN FILM	IC	
MEASUREMENT ACCURACY	Aver.	Aver.	Aver.	High
LONG-TERM STABILITY	Low	Aver.	Aver.	High
OUTPUT LEVEL	High	Low	Low	High
HYSTERESIS	Aver.	Aver.	Aver.	Low
CREEP	High.	Low	Low.	None
FREQUENCY RESPONSE	Fast	Limited	Aver.	Fast
MEDIA COMPATIBILITY	Limited	Limited	Limited	High
AGING EFFECTS	Aver.	Aver.	Aver.	Virtually None
PRESSURE RANGE	Limited	Limited	Limited	Broad
TEMPERATURE COMPENSATION	Extensive	Extensive	Extensive	Minimal
EMI/RFI SUSCEPTIBILITY	Aver.	High	High	Minimal
RUGGEDNESS & RELIABILITY	Fair-Low	Fair-Low	Fair-Low	High

Capacitive Pressure Transducer APPLICATIONS

Because they have earned a reputation for consistently high accuracy and unmatched long-term stability, Setra pressure sensors find broad application in areas where characteristics rate from important to vital. A few of these include:

Test & Measurement

- Turbo-jet/Turbo-fan aircraft engine test stands - internal pressure measurements at multiple points.
- Engine test stands for Autobus-Europe
- Wind tunnels
- Dynamometers
- Stack gas monitoring & analysis
- Medical instrumentation
- Hydraulic and Pitot static aircraft test systems
- A broad range of instruments, including laser interferometers, porosimetry instruments, particle measuring systems, automated sorption analyzers, etc.
- General R & D and Metrology Laboratory applications

Industrial & Military

- High-speed compressors
- Process control systems
- Canning/bottling systems
- Off-road vehicles
- Dairies - breweries
- Tank level measurement systems
- Helicopter missile-launch control systems
- Military surveillance equipment
- Semiconductor processing equipment
- Pharmaceutical and biotechnology processing
- Natural gas lines
- Off-shore drilling equipment
- Freeze drying equipment

Heating, Ventilating, Air Conditioning (HVAC)

- HVAC and VAV control systems
- Energy management systems
- Clean room control
- Filter condition monitoring
- Fume hood control
- Pump speed control
- Hospital isolation wards

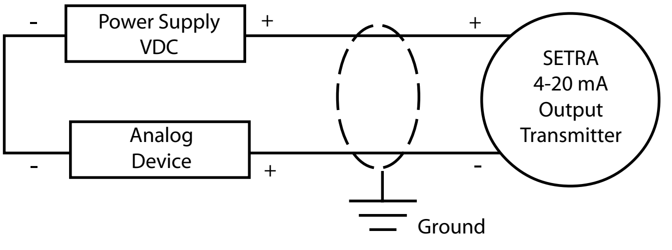
Barometric applications

- Presently in use at over 400 remote Land & Sea Weather Stations
- In use at over 500 airports as part of AWOS (Automated Weather Observing Systems) and ASOS (Automated Surface Observation Systems), for automatic barometric pressure reporting
- Used in weather stations throughout the U.S. and Canada
- In use by major weather systems manufacturers in Europe
- Widely used as transfer pressure standards
- Used by many airports and avionics shops for altimeter recertification

Electrical CONNECTIONS

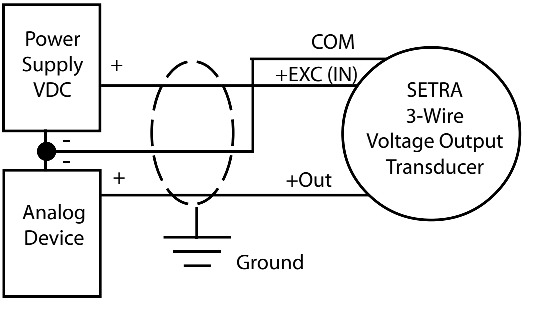
2-Terminal Transmitter Wiring

For use with all current output (4-20 mA) Models



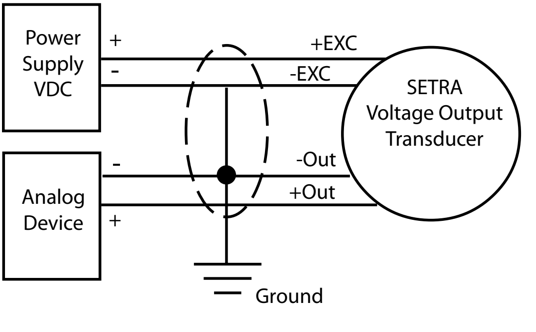
3-Terminal Transducer Wiring

For use with Setra Models 207, 264 and 280E



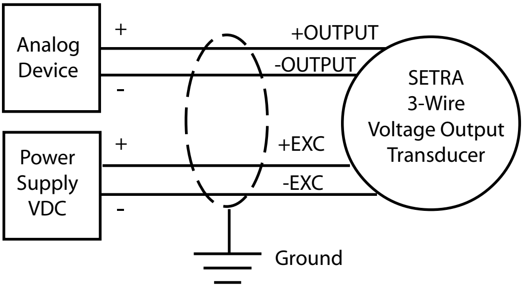
3-Terminal Transducer Wiring

For use with Setra Models 206, 209, 212FT, 276



4-Terminal Transducer Wiring

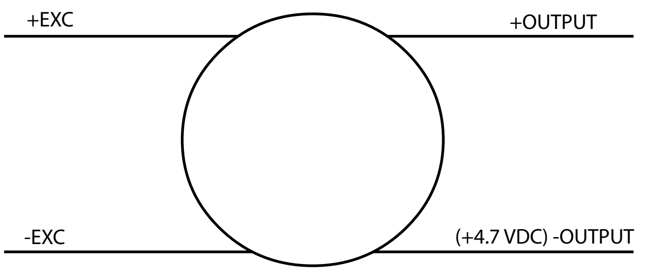
For use with Setra Models 204, 204D, 205-2, 206*, 212FT*, 239, and 270



*Models 206, 212FT can be wired as 3-wire devices by connecting -Output, -EXC and shield to a common ground.
4-wire transducers can only be grounded at either -EXC or on the -Output because a common mode voltage exits. (See Common Mode Voltage, below.)

Common Mode Voltage

4-Wire Models Only - Models 204, 204D, 205-2, 228-1, 239 and 270



Typically—OUTPUT is approximately 4.7 VDC above the -EXCITATION
Rule: You can only common or ground at one location—either -EXC or -OUTPUT

Specifications
DERIVATIONS

Accuracy

Expressed in %FS at constant temperature
Accuracy as RSS non-linearity, hysteresis and non-repeatability

Root Sum Squares (RSS)

Non-Linearity $(\pm 0.1\%)^2$ = 0.01%

Hysteresis $(\pm 0.05\%)^2$ = 0.0025%

Non-Repeatability: $(\pm 0.02\%)^2$ = 0.0004%

0.0129%

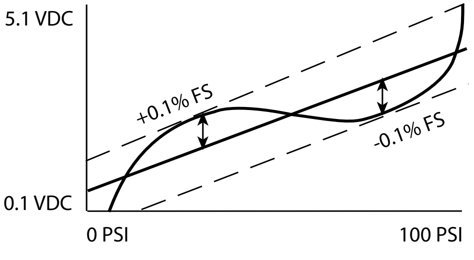
$\sqrt{0.0129\%}$ = ±0.11% FS at constant temperature

Non-Linearity

Relationship of a calibration curve to a specified straight line.

Best Fit Straight Line (BFSL) Method

Example: ±0.1% FS



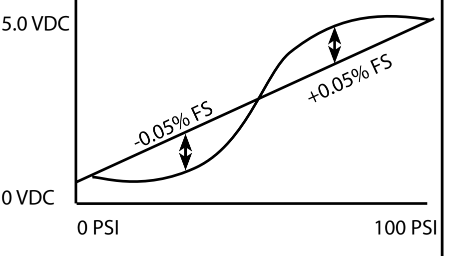
Used for non-linearity measurement on all Setra Pressure Transducers except Model 270, 276, 370 and 470.

Non-Linearity

Relationship of a calibration curve to a specified straight line through its end points.

End Point Method

Example: ±0.05% FS



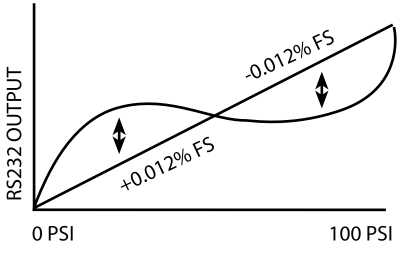
Used for non-linearity measurement on Models 270 and 276.

Non-Linearity

Relationship of a calibration curve to a specified straight line with end points at zero and full scale.

Terminal Method

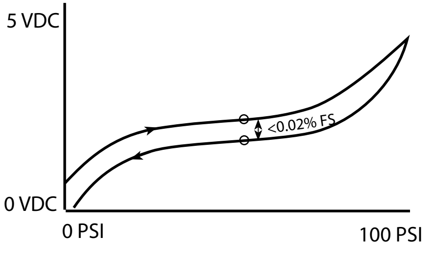
Example: ±0.012% FS



Used for non-linearity measurements on Models 370 and 470.

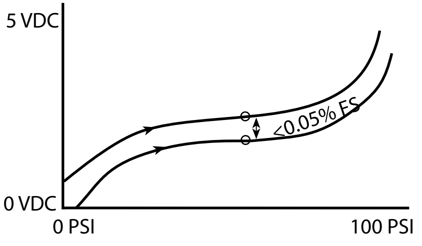
Hysteresis

The maximum difference in output at any pressure value within the specified range, **when the value is approached with increasing and decreasing pressure.**



Non-Repeatability

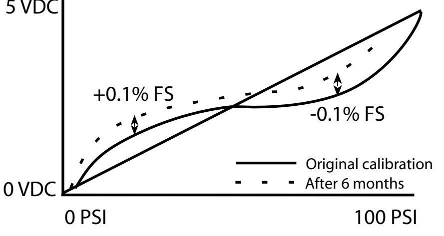
The ability of a transducer to reproduce output readings **when the same pressure value is applied to it consecutively, under the same conditions, and from the same direction.**



Long Term Stability

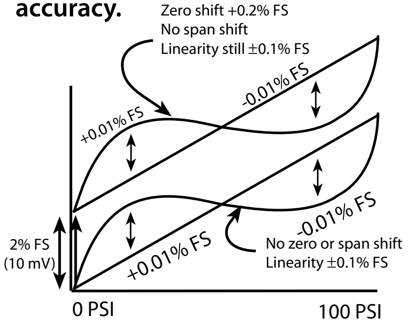
The ability of a transducer to reproduce output readings obtained during its original calibration **at room conditions for a specified period of time.**

Example: (Model 270):
±0.1% FS over 6 Months
at 70°F (21°C)



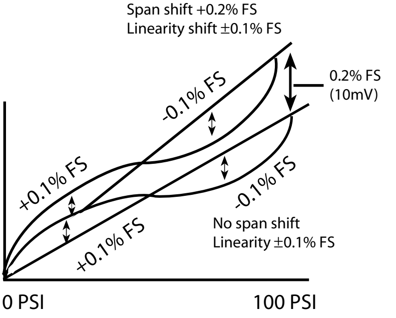
Zero Offset

Zero output is factory set to within a certain % of full scale. Results in a shift up or down of the calibration curve. **Does not affect linearity or accuracy.**



Span Offset

Span output is factory set to within a certain % of full scale. Results in a change in the slop of the curve.
Does not affect linearity or accuracy.



Thermal Effects

The change in the zero and span output that occurs due to temperature changes.

Thermal Zero Shift: <±0.4% FS/100°F
Thermal Span Shift: <±0.3% FS/100°F

Example Temp. Range -10°F to ±130°F

Max. temp change from 70°F = 80°F

80°F x 0.4% = 0.32% FS DZ/DT
80°F x 0.3% = 0.24% FS DZ/DT
Z shift = <±0.32% FS
S shift = <±0.24% FS

Total Error Band

(Worst Case) Over a Temperature Range of -10°F to 130°F

Non-Linearity:	±0.1% FS
Hysteresis:	±0.05% FS
Non-Repeatability:	±0.02% FS
Thermal Zero Shift:	<±0.32% FS
Thermal Span Shift:	<±0.24% FS
Zero Offset:	±0.2% FS
Span Offset:	±0.2% FS
	±1.13% FS

Long-term stability error not included.

GLOSSARY of Pressure Terms

Absolute Pressure — Pressure measured relative to a full vacuum. Referred to as pounds per square inch absolute (PSIA).

Atmospheric Pressure — Pressure of the atmosphere at the earth's surface NIST standard atmospheric pressure = 1.01325 bar.

Bar — Unit of pressure (or stress). 1 bar = 750.07 mm of mercury at 0°C, lat. 45°

Barometric Pressure— Atmospheric pressure; often measured in millibars, in. Hg (inches of mercury), or hectopascals.

Bourdon Tube — An early, mechanical pressure gauge consisting of a flattened tube that tends to straighten under internal pressure; today usually used with a potentiometer to produce an electrical output.

Burst Pressure — The maximum pressure that may be applied to the positive pressure port without rupturing the sensing element.

Capacitive Sensing — Detection and measurement of pressure through the change in voltage across a capacitor, one plate of which is a diaphragm which deflects slightly with changes in applied pressure.

Compound Pressure — Pressure measured from full vacuum (-14.7 PSIV) to gauge pressure, referencing atmosphere.

Differential Pressure — Pressure measured relative to a reference pressure. Referred to as pounds per square inch differential (PSID).

FS (Full Span or Full Scale) — The range of measurand values over which a transducer is intended to measure, specified by the upper and lower limits. Ex: 0 to 100 PSIG, FS is 100 PSIG/ 0 to 5 VDC, FS is 5 VDC, 800-1100 MB, FS is 300 MB.

Gauge Pressure — Pressure measured relative to ambient atmospheric pressure. Quantified in pounds per square inch gauge (PSIG).

Manometer— An early instrument for measuring pressure; originally a U-shaped tube containing liquid (water, oil or mercury), one limb opening to the gas volume to be measured, the other closed or connected to a registering or recording instrument. Modern versions utilize diaphragms, bellows or other devices for sensing relative pressures.

Millibar (mbar) — Unit of pressure generally used in barometric measurements; 1 mbar = 100 N/m^2, or 1~ dyn/cm^2

Newton (N) — The unit of force in the International System of Units (SI); the force required to impart an acceleration of 1 m/sec^2 to a mass of 1 kg.

Pascal (Pa)—The standard unit of pressure (or stress) in the SI system: equal to 1 newton per square meter (1 N/m^2).

P/I — Term common to process industries meaning pressure-in/current-out. (3-15 PSIG Input to 4-20 mADC Output.).

Pressure Transducer — An electromechanical device for translating pressure values into voltages across a high-impedance (5k ohms or greater) load.

Pressure Transmitter — An electromechanical device for translating pressure values into currents (generally 4-20 mA) into a low-impedance load.

Proof Pressure — The maximum pressure that may be applied without changing performance beyond specifications (typically, 0.5% FS zero shift).

PSIA — Pounds per square inch absolute.

PSIV — Pounds per square inch vacuum.

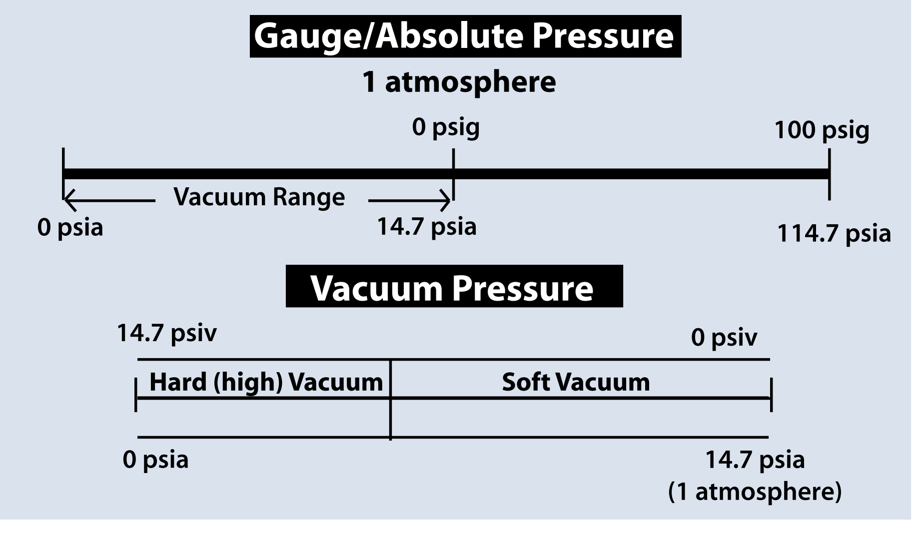
Range — The spread between the maximum and minimum pressures between which the transducer has been designed to operate.

Setraceram™ — A patented, ceramic/glass sensing element, used by Setra in barometric transducers and instruments requiring the highest degree of measurement precision and stability.

Span — The algebraic difference between the limits of the range. EX: 0.1 to 5.1 Volts DC; span is 5 VDC. Sometimes used to designate full scale output; i.e. 5 VDC.

Torr — A unit of low pressure equal to a head of 1 mm of mercury, or 133.3 N/m^2.

Vacuum — Generally refers to pressures between 0 and atmospheric; often measured in 0-30 in. Hg Vacuum. Referred to as pounds per square inch vacuum (PSIV).



Typical Application \ Setra Transducer Model	Model 204 High Acc. - T&M	Model 205-2 GP T&M	Model 206/207 Industrial/OEM	Model 209 Industrial/OEM	Model 270/370/470 Barometric/Med. Pressure	Model 280E High Press./GP Processing	Model 204D High Diff. Pressure	Model 230 Wet/Wet Diff. Pressure	Model 239 High Acc. Low Diff. Pressure	Model 264/265/260 Low Diff. Pressure (HVAC)	Model 212FT Flow-Thru - UHP	Model 280E-XP High Press. - Expl.-Proof	Model C-290 Flush Diaph - 3A Sanitary	Model 276/278 OEM Barometric
Altimeter Setting					●									
Barometric Measurements					●									
Chillers			●	●										
Clean Room Control										●				
Compressor Control			●	●										
Dynamometers		●												●
Energy Management										●				
Engine Test Cells	●	●				●	●							
Filter Condition Monitors								●		●				
Food & Beverage Process													●	
Fume Hood Control									●	●				
Gas Bottle Filling Equipment											●			
General Purpose/Industr.		●	●			●	●							
Hazardous Locations	●						●					●		
High Acc. Test & Measm't	●	●			●	●	●		●					
HPLC											●			
HVAC/VAV Control				●				●	●	●				
HVAC Equipment				●				●						
Hydraulic/Pneumatic Sys.			●	●		●								
Intrinsically Safe Duty	●	●					●		●					
Industrial Engine				●										
Laser Interferometers					●									●
Leak Detection									●					
Level Measurement					●	●		●					●	
Medical Instrumentation				●					●	●				
Natural Gas Lines				●								●		
OEM Applications			●	●	●			●		●	●		●	●
Off Road Vehicles				●										
Off Shore Drilling				●				●				●		
Paper Converting Syst.			●											
P/I Range						●								
Pharmaceutical Process											●		●	
Pressure Transfer Stds.					●									
Process Control						●		●				●		
Pump Speed Control			●	●				●						
Refrigeration Equipment								●						
R&D Scientific	●	●			●			●	●					
Sanitary Filtration System											●		●	
Sanitary Pressure Lines											●		●	
Semicon Equipment					●				●		●			●
Specialty Gas Handling											●			
Test & Measurement	●	●			●		●		●					
Weather Data Systems					●									●
Vacuum Systems	●	●			●	●								●

SPECIFYING
Capacitive Pressure Transducers

The following guide will assist you in selecting the type and ratings of the Setra pressure transducer that will do your job best. If you would like a quotation, just fax or mail us a copy of this form for quick response.

Application

Application is ❒ New ❒ Existing Describe ______________________

____

____

____

Model # (if known) ____________ Inital Qty _________ Est. Annual Qty _____________

Pressure Range: _____________ ❒ Gauge ❒ Absolute ❒ Differential ❒ Vacuum

Output: ❒ 0-5 VDC ❒ 1-6 VDC ❒ 4-20 mA ❒ 0.1 to 5.1 VDC ❒ Other _________

Excitation: ❒ 24 VDC ❒ 12 VDC ❒ Other _________________

Media: ❒ Air ❒ Water ❒ Hydraulic Fluid ❒ Other ____________

Environment: ❒ Indoor ❒ Outdoor ❒ Explosion-Proof ❒ Other _____________

Pressure Fitting: ❒ 1/4" NPT (Male) ❒ Flush ❒ 7/16" SAE (male) ❒ Other ________

Electrical Termination: ❒ ________________ ft. Cable (specify length)

❒ Terminal Strip ❒ Other

Temperature Exposure (operating): ❒ 40°F - 100°F ❒ 0 to 175°F ❒-40°F - 185°F

❒ Other __________

Shock: ❒ 50G ❒ 100G ❒ 200G ❒ Other ____________

Vibration: ❒ 5G ❒ 10G ❒ 20G ❒ Other ____________

Electrical Interference: Specify Potential Noise (field strength & frequency)

Options: ____

____

Remarks ____

____

____

Name: ____________________________________ Title: __________________________

Organization: ______________________________ Division: ______________________

Address: ____

City/State/Zip: ____

Phone: (   ) ______________________________ Fax : (   ) _____________________

Email: ____________________________________

PRESSURE CONVERSION CHART
Multiplication Factors

TO \ FROM	PSI (lb/in²)	BAR	MILLIBAR Hectopascal	IN.HG (at 0°C)	IN.H_20 (at 4°C)	MM HG (at 0°C)	MM H_2O (at 4°C)	PASCAL (N/m²)	ATM	TORR
PSI (lb/in²)	1	14.5039	1.4504×10^{-2}	.491159	3.6127×10^{-2}	1.93368×10^{-2}	1.4223×10^{-3}	1.45038×10^{-4}	14.6960	1.9337×10^{-2}
BAR	6.8947×10^{-2}	1	1×10^{-3}	3.3865×10^{-1}	2.4908×10^{-3}	1.3332×10^{-4}	9.8068×10^{-5}	1×10^{-5}	1.0132	1.3332×10^{-3}
MILLIBAR Hectopascal	68.947	1×10^{3}	1	33.865	2.4908	1.3332	9.8068×10^{-2}	1×10^{-2}	1.0132×10^{3}	1.3332
IN.HG (at 0°C)	2.0360	29.529	2.9529×10^{-2}	1	7.3552×10^{-2}	3.9368×10^{-2}	2.8959×10^{-3}	2.9529×10^{-4}	29.920	3.9368×10^{-2}
IN. H_2O (at 4°C)	27.680	401.47	.40147	13.596	1	.53525	3.9372×10^{-2}	4.0147×10^{-3}	406.78	.53525
MM HG (at 0°C)	51.7149	750.06	.75006	25.401	1.8683	1	7.3558×10^{-2}	7.5006×10^{-3}	760.00	1
MM H_2O (at 4°C)	703.08	1.0197×10^{4}	10.197	345.32	25.399	13.595	1	.10197	1.0332×10^{4}	13.595
PASCAL (N/m²)	6894.76	1×10^{5}	100	3.3865×10^{3}	249.08	133.32	9.8068	1	1.0132×10^{5}	133.32
ATM	6.8046×10^{-2}	.98692	9.8692×10^{-4}	3.3422×10^{-3}	2.4583×10^{-3}	1.3158×10^{-3}	9.6788×10^{-5}	9.8692×10^{-6}	1	1.3158×10^{-3}
TORR	51.7149	750.06	.75006	25.401	1.8683	1	7.3558×10^{-2}	7.5006×10^{-3}	760.00	1

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