PRESSURE AND ACOUSTICS

THE MODAL SHOP

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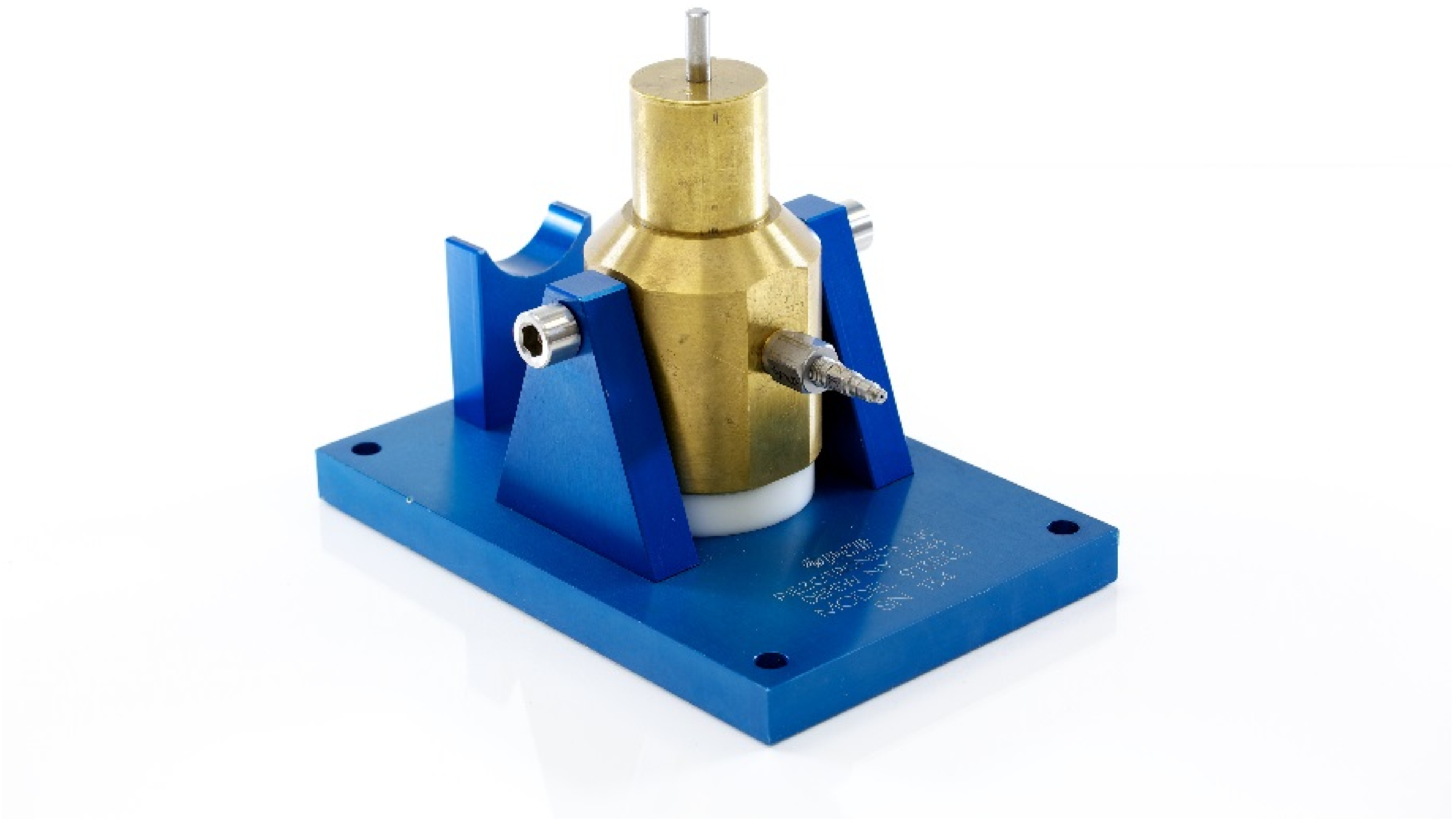
APRIL 2019

TODAY'S AGENDA

- Pressure Sensors vs. Condenser Microphones
- Pressure Sensor Design
- Acoustic Microphone Design
- Calibration Techniques For Both



PRESSURE SENSOR VS. MICROPHONES

Pressure Sensors

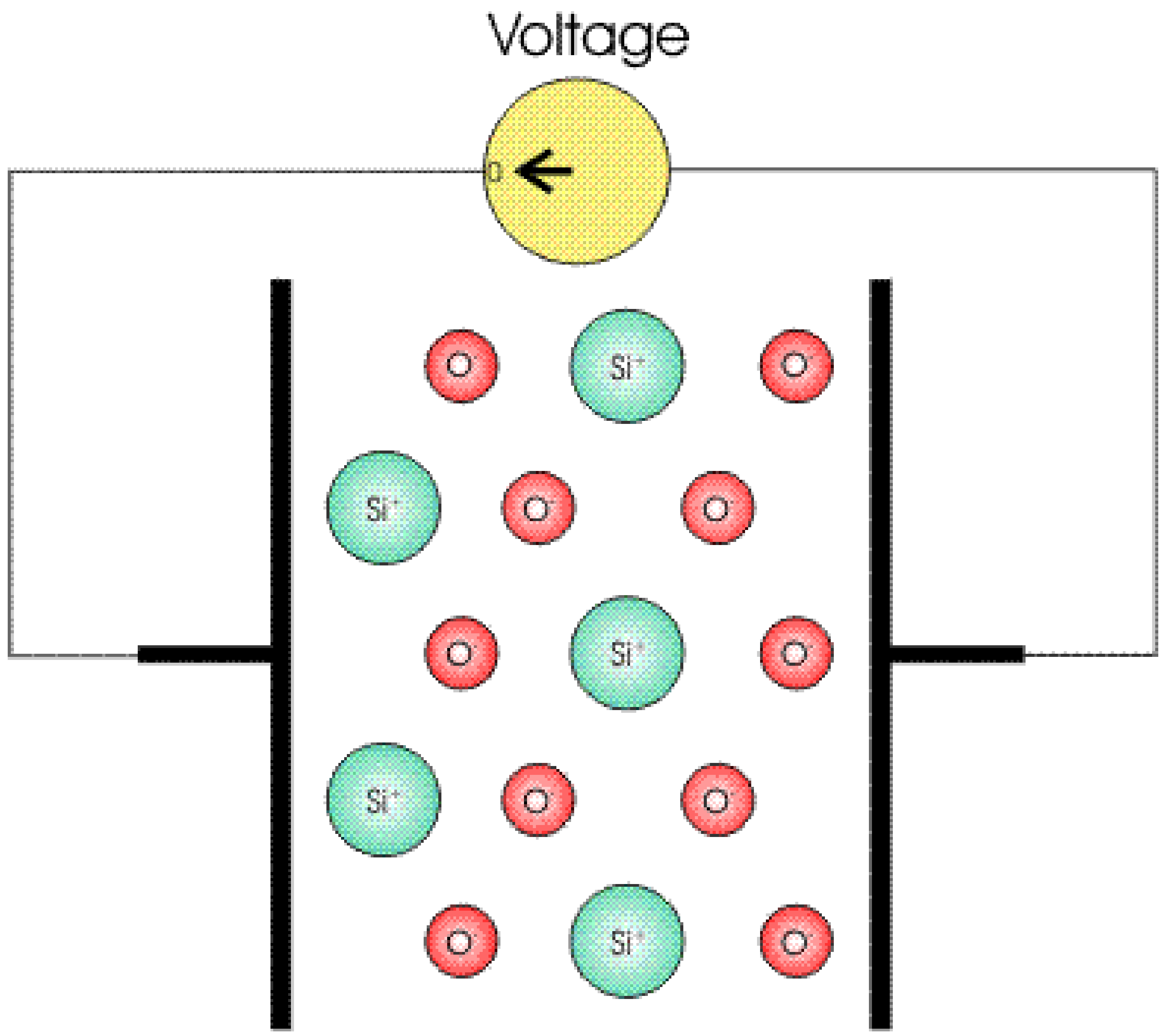
- Piezoelectric
- Full Scale: Varies by design.
  - 7kPa [1 psi]
  - 700 MPa [100 ksi]
- Rugged
- Operation to 650° C
- Wide Variety of Form Factors

Condenser Microphones

- Variable Capacitance
- Full Scale: Varies by design
  - 600 Pa [150 dB SPL]
  - 20 kPa [180 dB SPL]
- Relatively Fragile
- Operation to 120° C
- Standardized Sizes

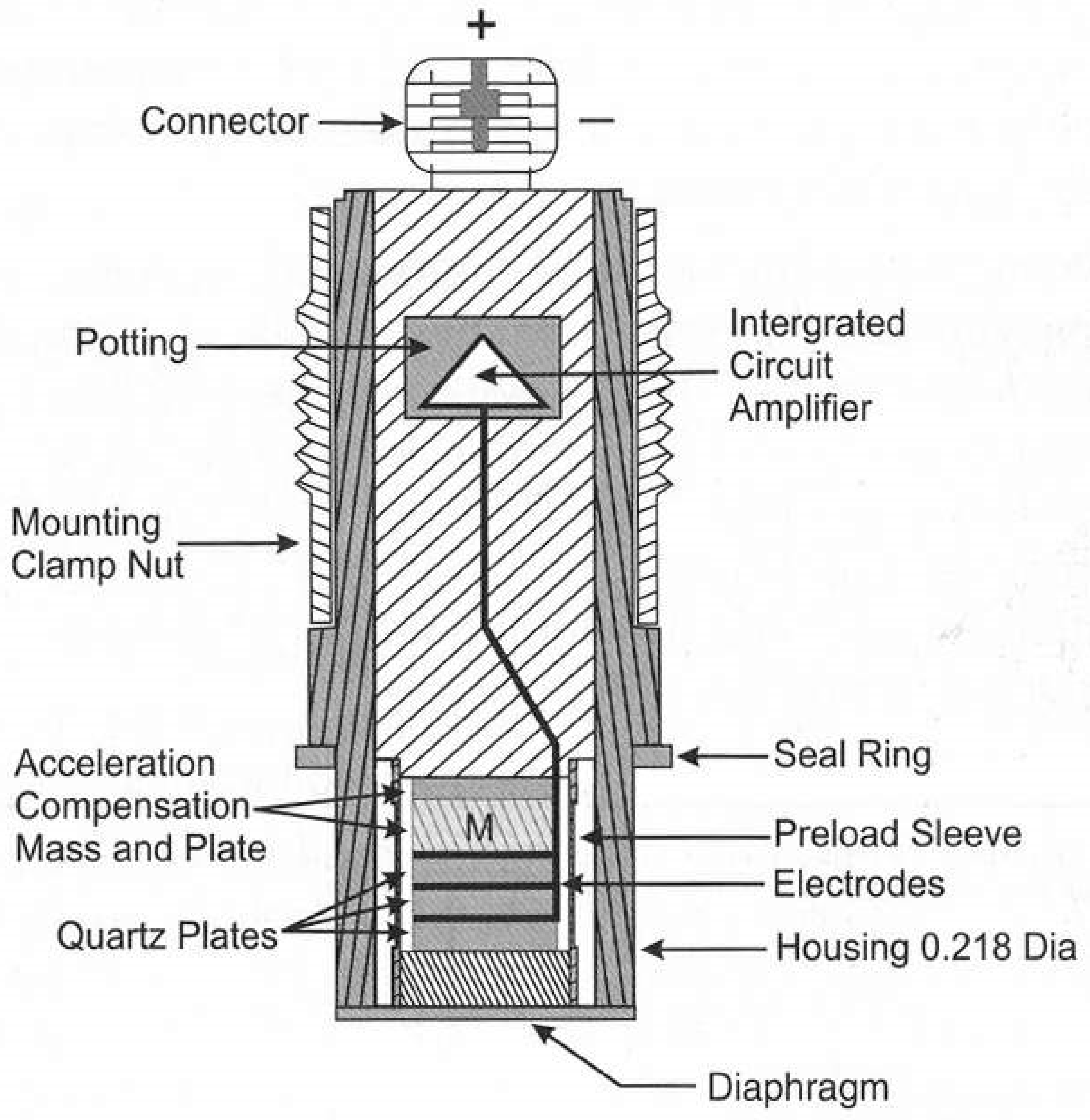
PRESSURE SENSOR – SENSING ELEMENT

- Sensing element is usually quartz
  - Naturally occurring
  - Stable
  - Insensitive to temperature transients
- Alternative is ceramic
  - Pyroelectric output
  - Aging causes logarithmic decay of output



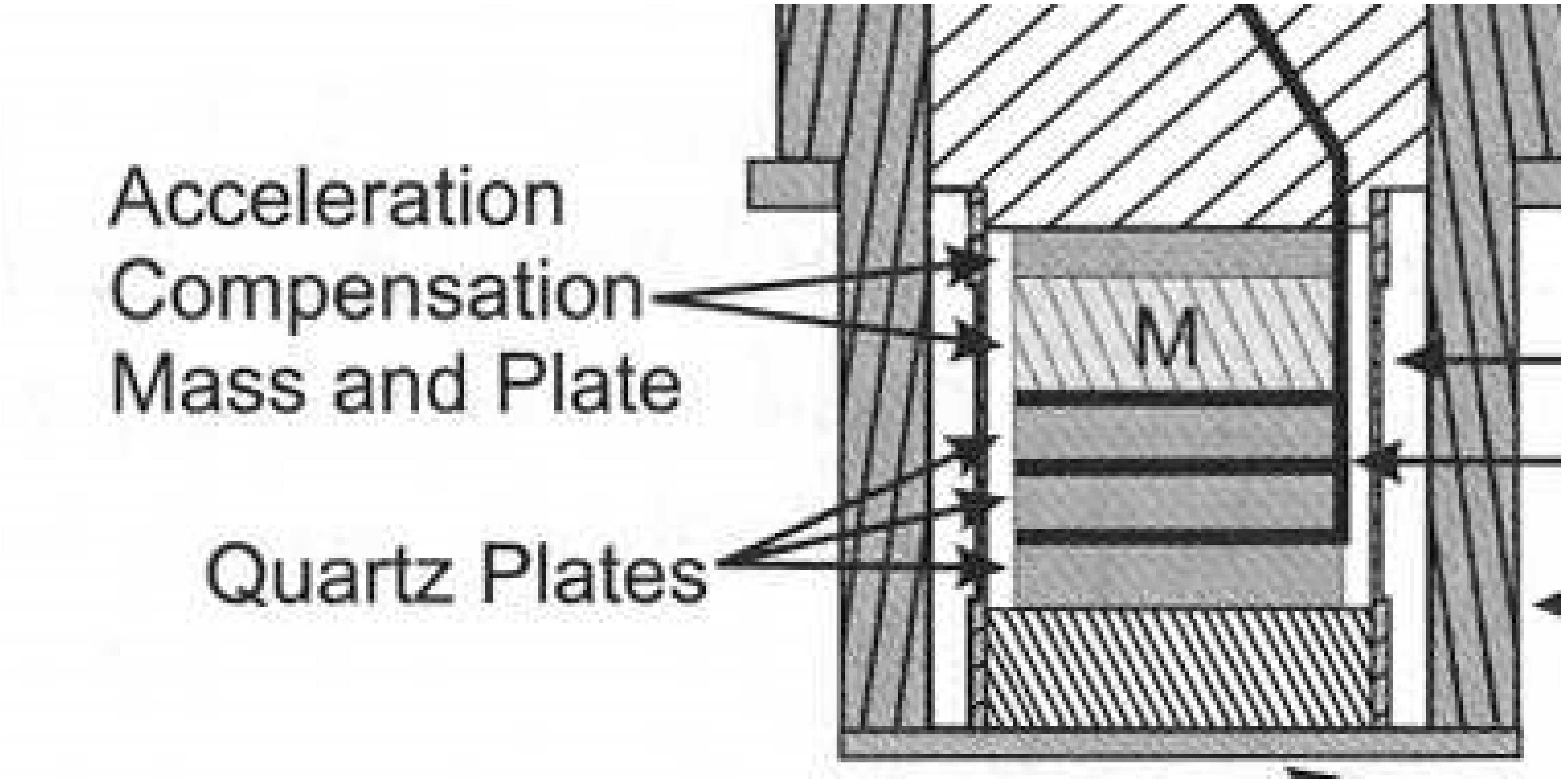
PRESSURE SENSOR – SENSING ELEMENT

- Quartz is arranged in compression geometry
- High impedance output from crystal is amplified
    - Internally to the sensor
    - Externally for high temperatures
- Fairly massive diaphragm
- 2 wire output



PRESSURE SENSOR – SENSING ELEMENT

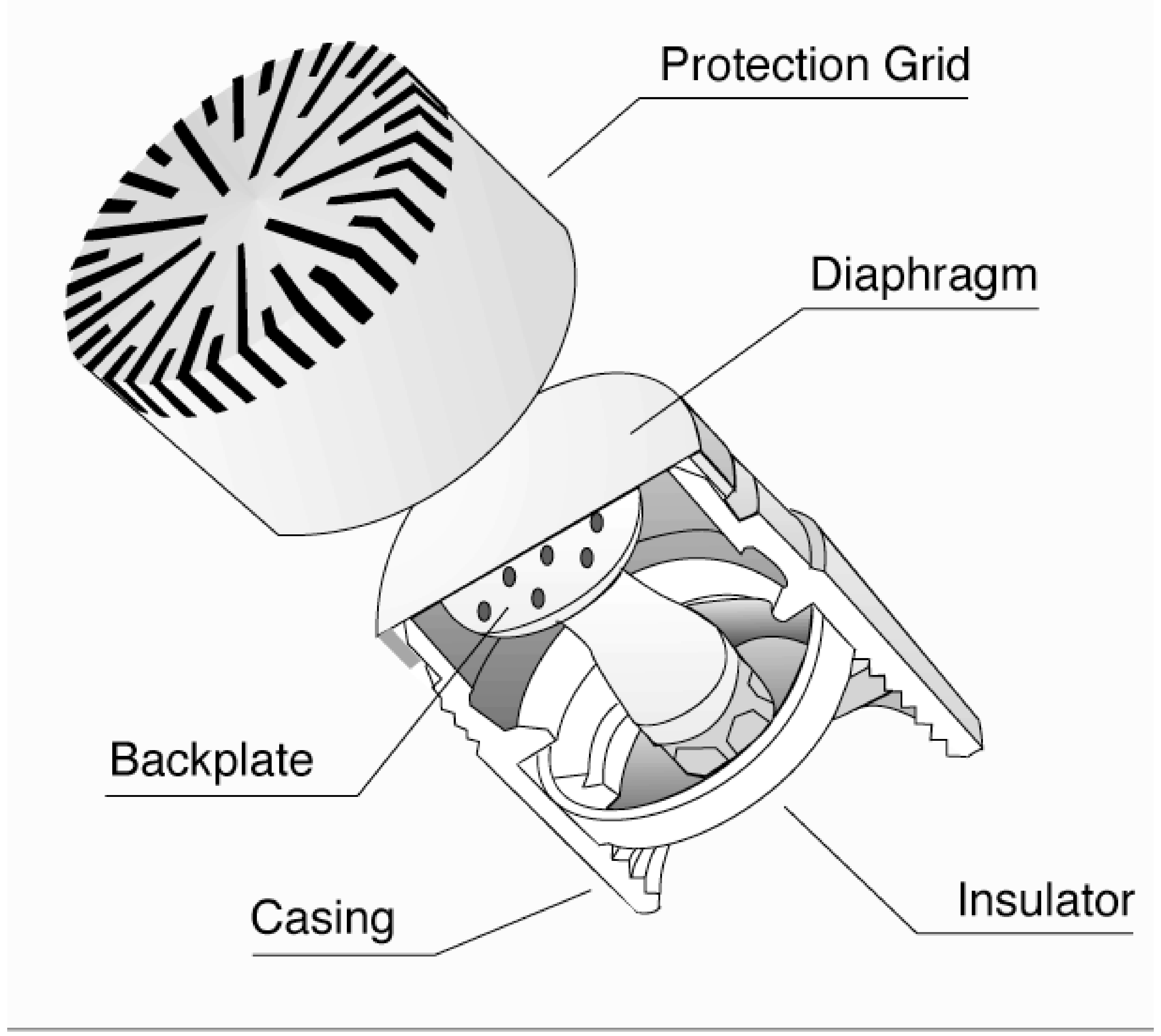
- Acceleration Compensation
- Creates a small accelerometer
  - Signal is subtracted from the pressure signal



ACOUSTIC MICROPHONE – SENSING ELEMENT

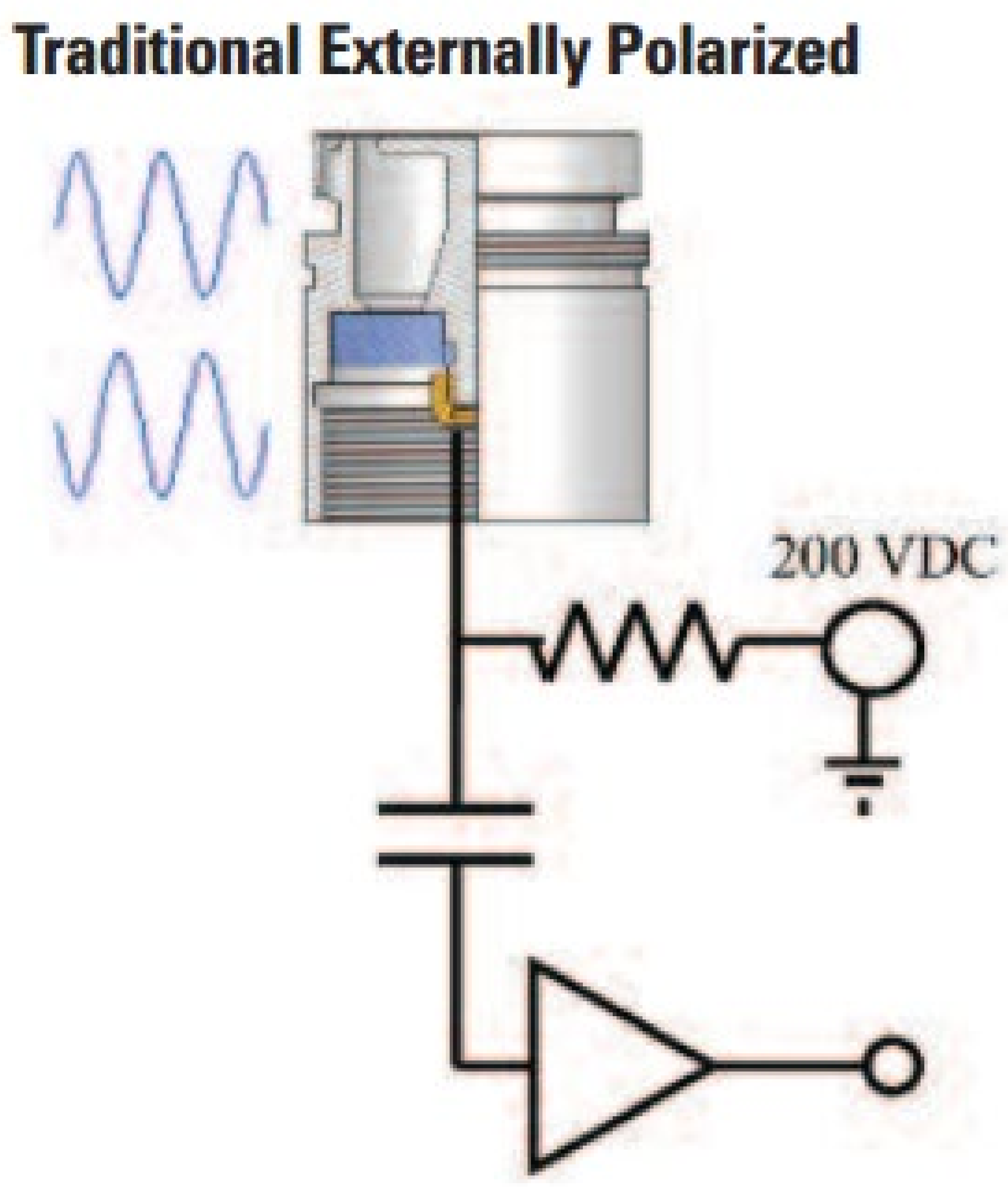
- Varying capacitance creates a varying output voltage
  - Diaphragm
  - Backplate
- Very thin diaphragm
  - High sensitivity
  - Fragility
- Standard diaphragm diameters : ¼", ½", 1"

- Low frequency response determined by acoustic venting



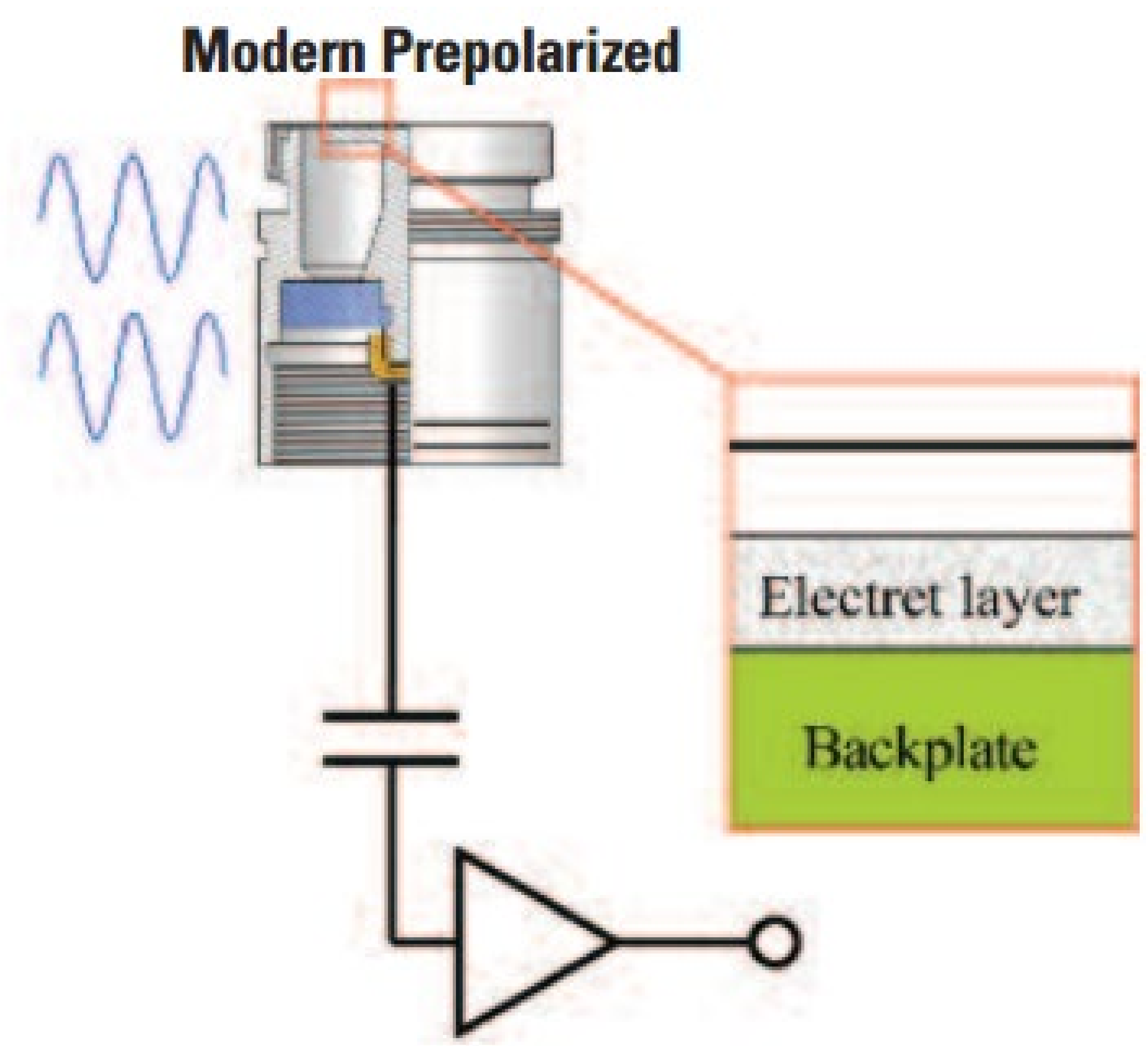
ACOUSTIC MICROPHONE – SIGNAL CONDITIONING

- Capacitor must be polarized
- Externally polarized
  - 200 V DC
  - External source
- Preamplifier required
  - Multiple pin LEMO



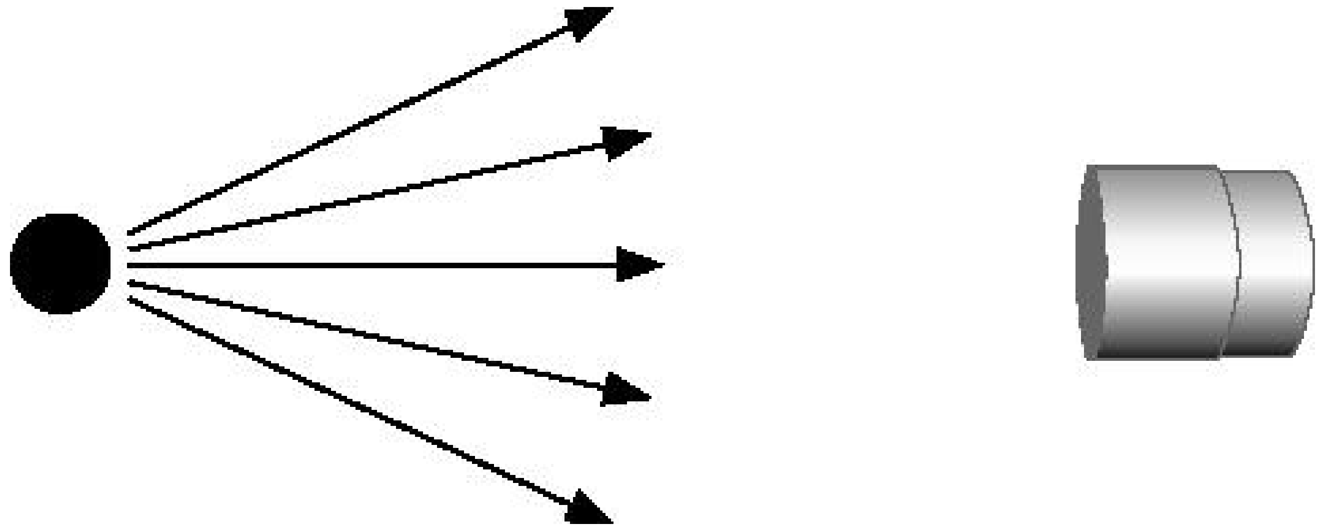
ACOUSTIC MICROPHONE – SIGNAL CONDITIONING

- Capacitor must be polarized
- Prepolarized Backplate
  - Enables simple 2-wire cabling
  - Embedded electronics for ICP® operation
- Interchangeable with ICP® accelerometers and pressure sensors on a single DAQ channel
- Preamplifier required
  - Usually ICP – coaxial connector



CONDENSER MICROPHONES – FREE FIELD RESPONSE

- Free Field Response
- Designed for single pressure sources
- Modeled as 0 degree incidence
- Low reflection environment
- Frequency dependent corrections applied



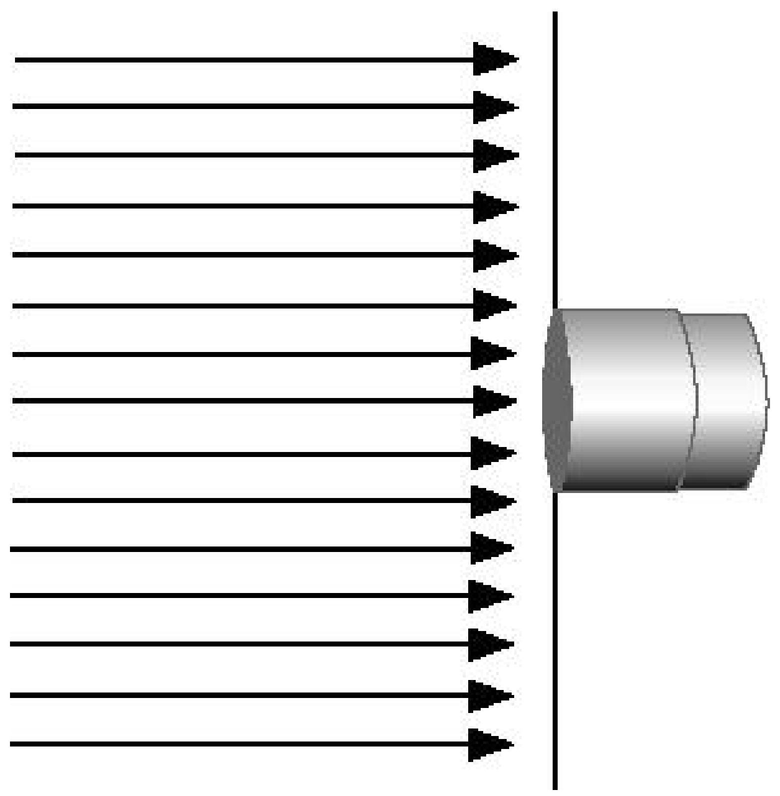
CONDENSER MICROPHONES – PRESSURE FIELD RESPONSE

- Measures pressure at diaphragm

- aka wall mounted

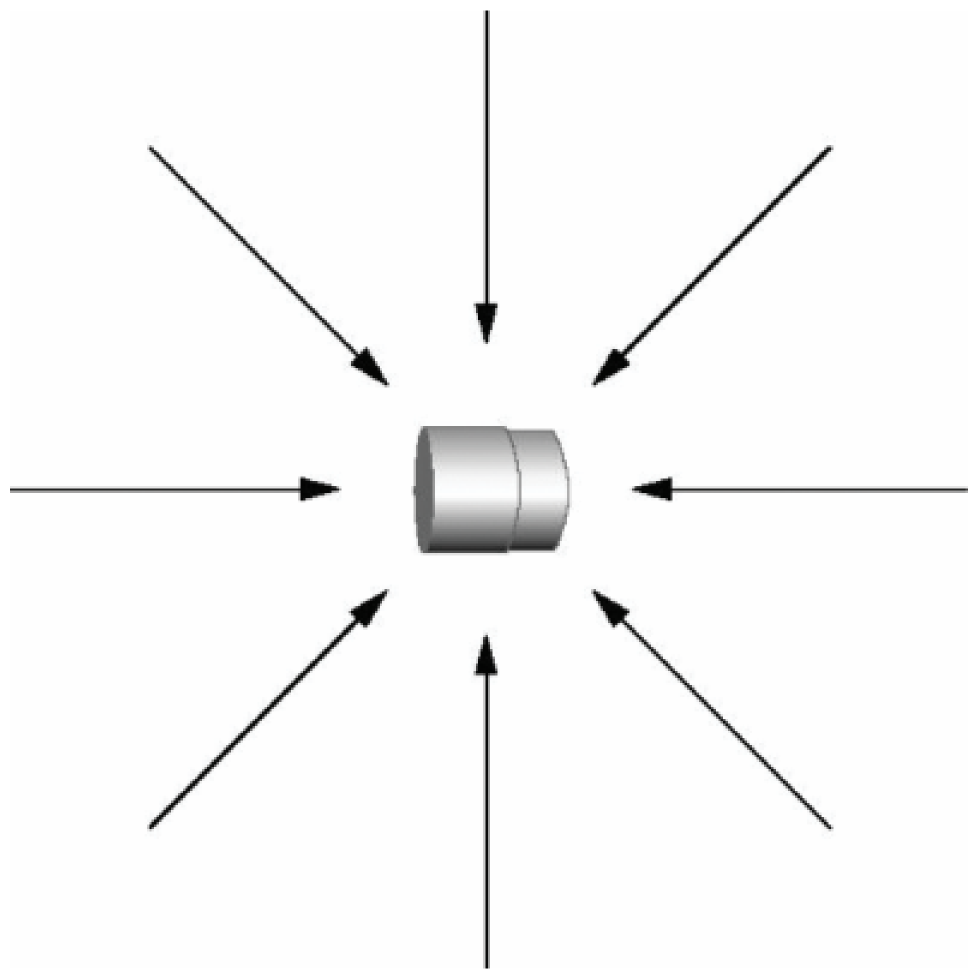
- Microphone is 'built in' to the existing boundary condition

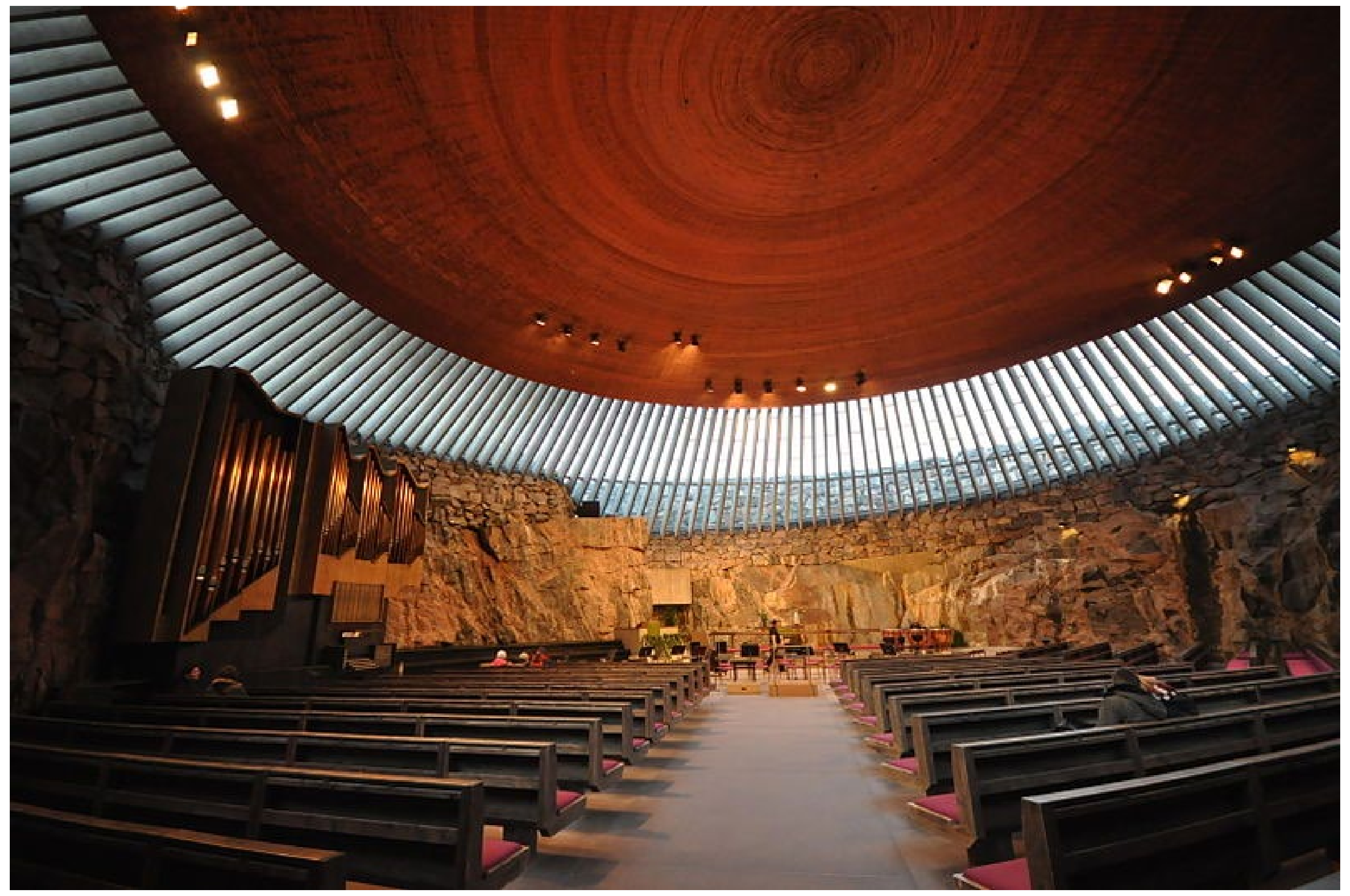
- Models pressure as equal throughout the field



CONDENSER MICROPHONES – RANDOM INCIDENCE RESPONSE

- Random incidence, aka diffuse field
- Modeled as omni-directional sources
- Used in highly reflective environments
- Frequency dependent corrections specific to manufacturer





PRESSURE SENSOR SOUND FIELD INTERACTION

- Primarily pressure field measurements
- Special designs for applications like free-field blast

CALIBRATION

- Microphone calibration
  - Reciprocity
  - Insert voltage
  - Electrostatic actuator

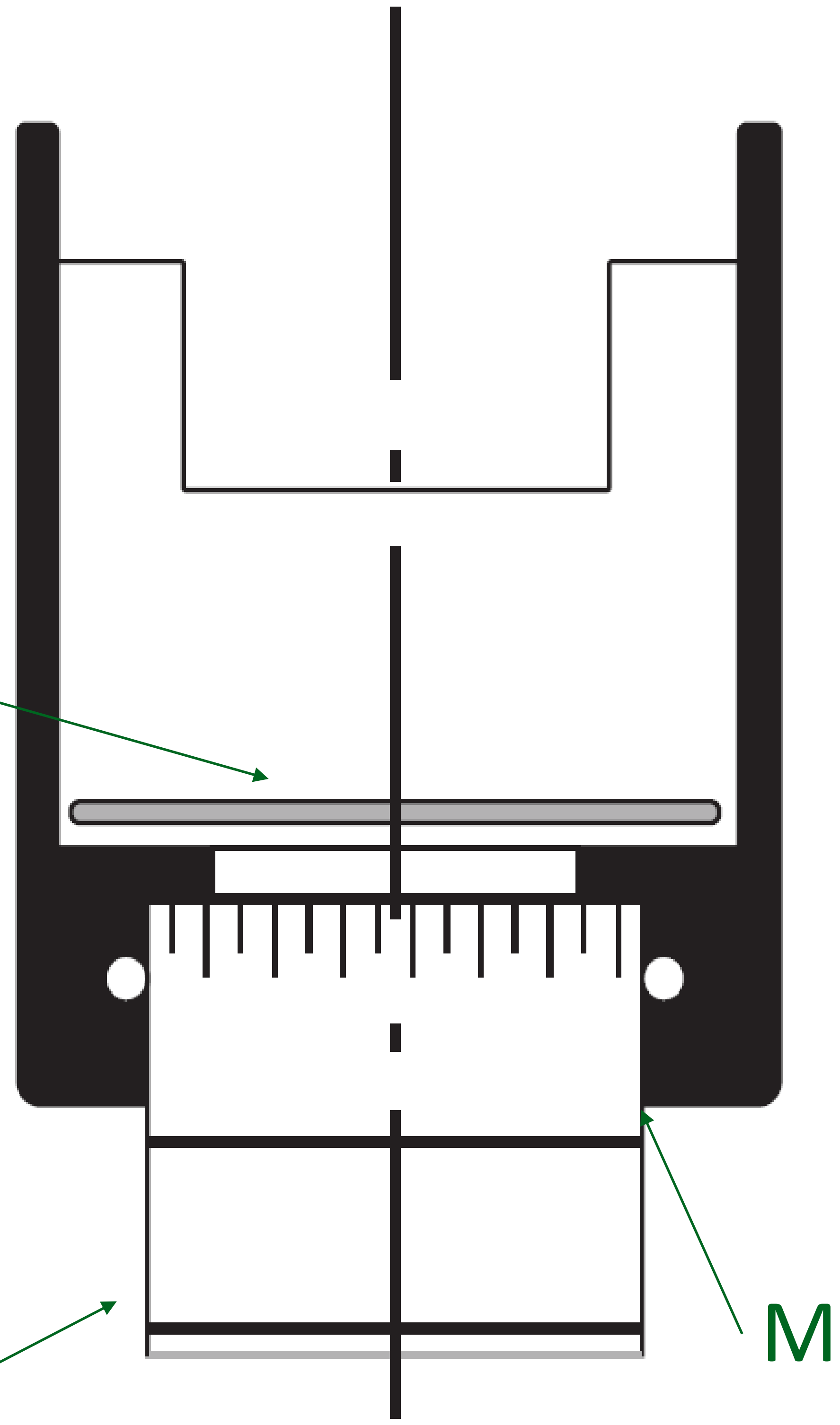
- Pressure sensor calibration
  - Step method
  - Impulse method
  - Media
    - Pneumatic
    - Inert gas
    - Oil

CALIBRATION – CONDENSER MICROPHONES

- **IEC 61094 defines**
  - Condenser microphones
  - Calibration methods
- **Calibration methods**
  - Reciprocity
    - For primary
  - Pistonphone or speakerphone
    - For field check
- Insert voltage
  - Laboratory calibration
- Electrostatic actuator
  - Frequency response in laboratory
- Comparison Method

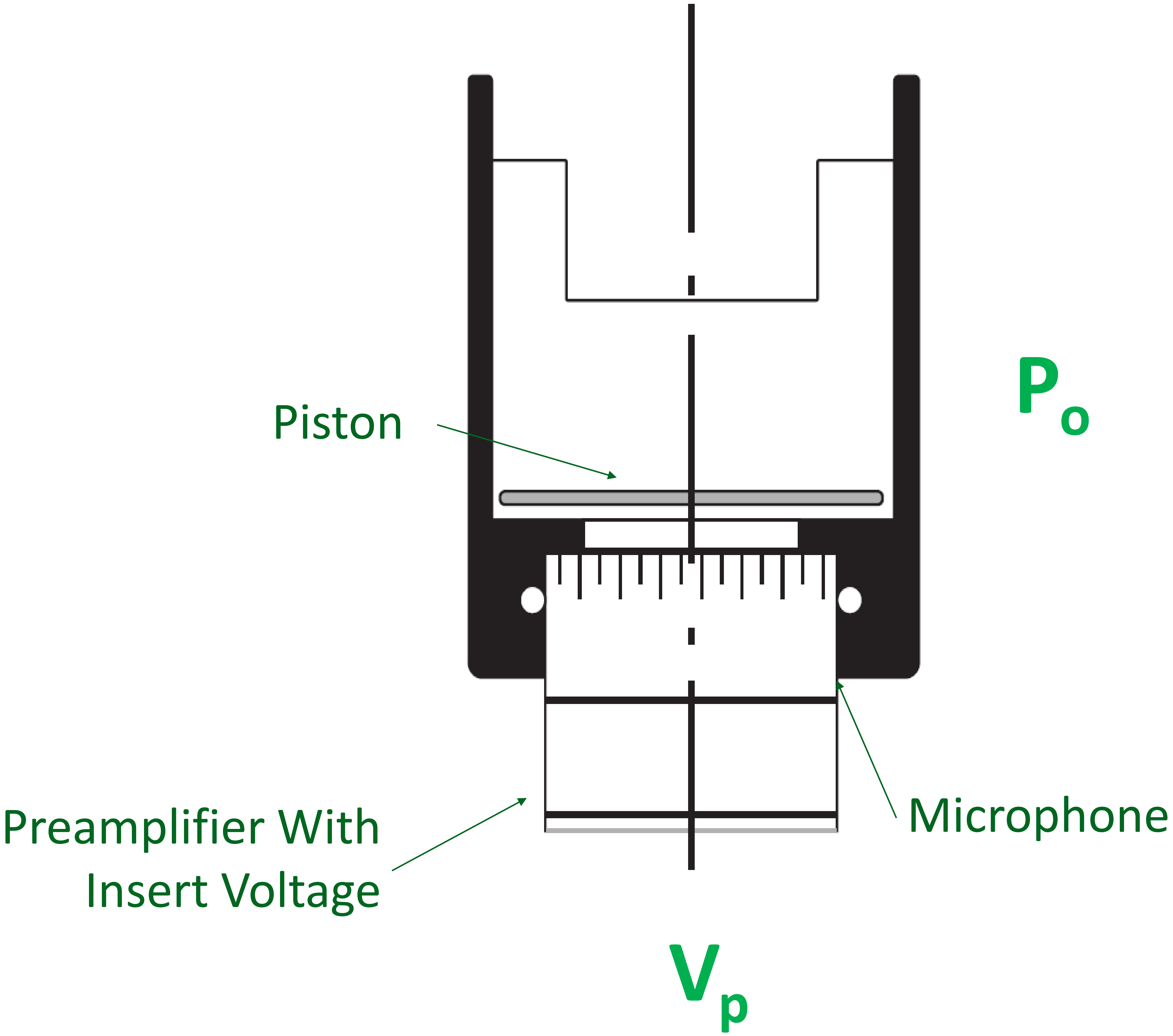
INSERT VOLTAGE TECHNIQUE

- Components
  - Sound Source
    - Sound Calibrator
    - Pistonphone (shown)
  - MUT Microphone Under Test
  - Preamplifier With Insert Voltage Option



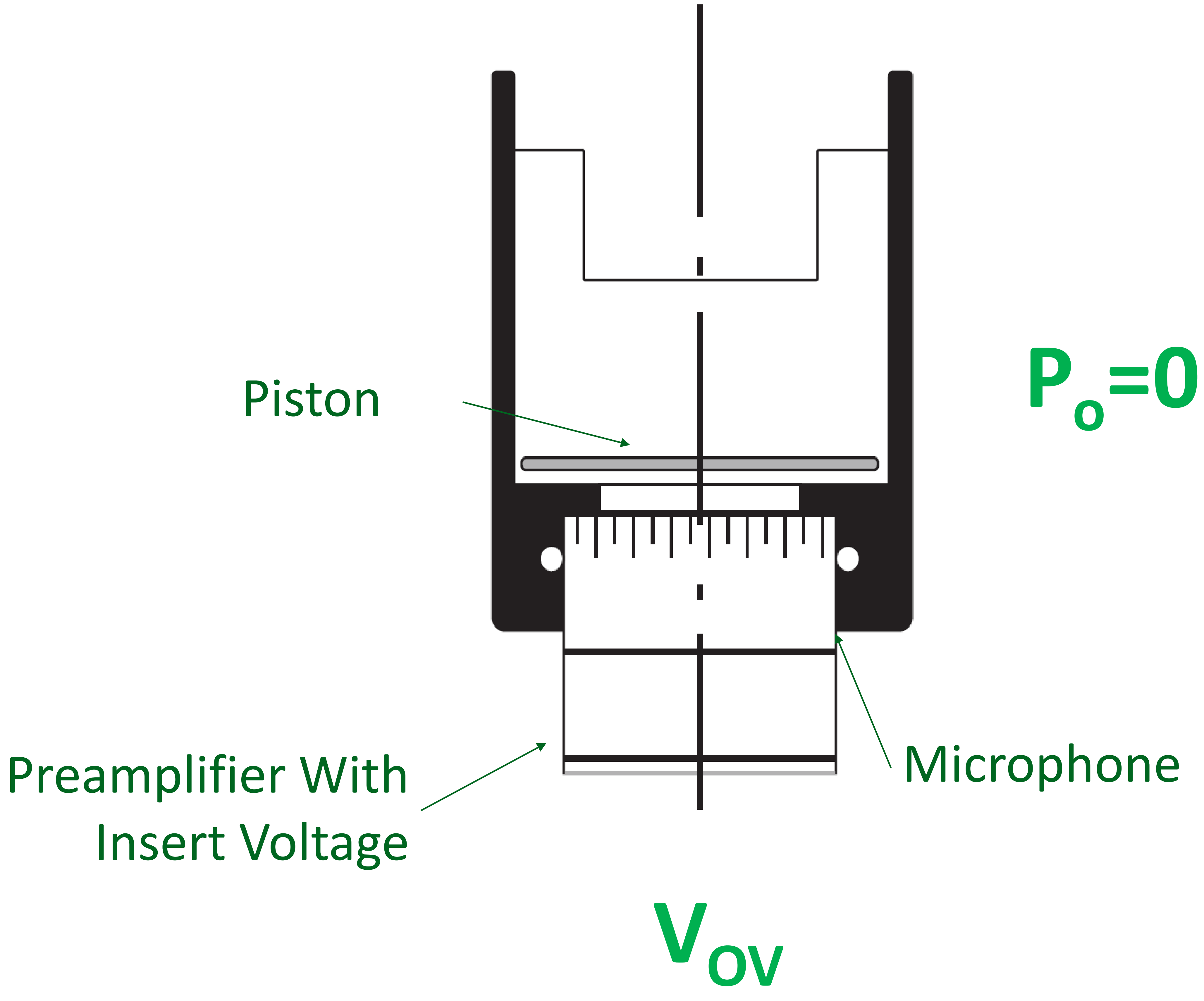
INSERT VOLTAGE TECHNIQUE

- Step 1
  - Piston creates oscillating pressure P_0.
  - Measure Preamp Output Voltage V_p.



INSERT VOLTAGE TECHNIQUE

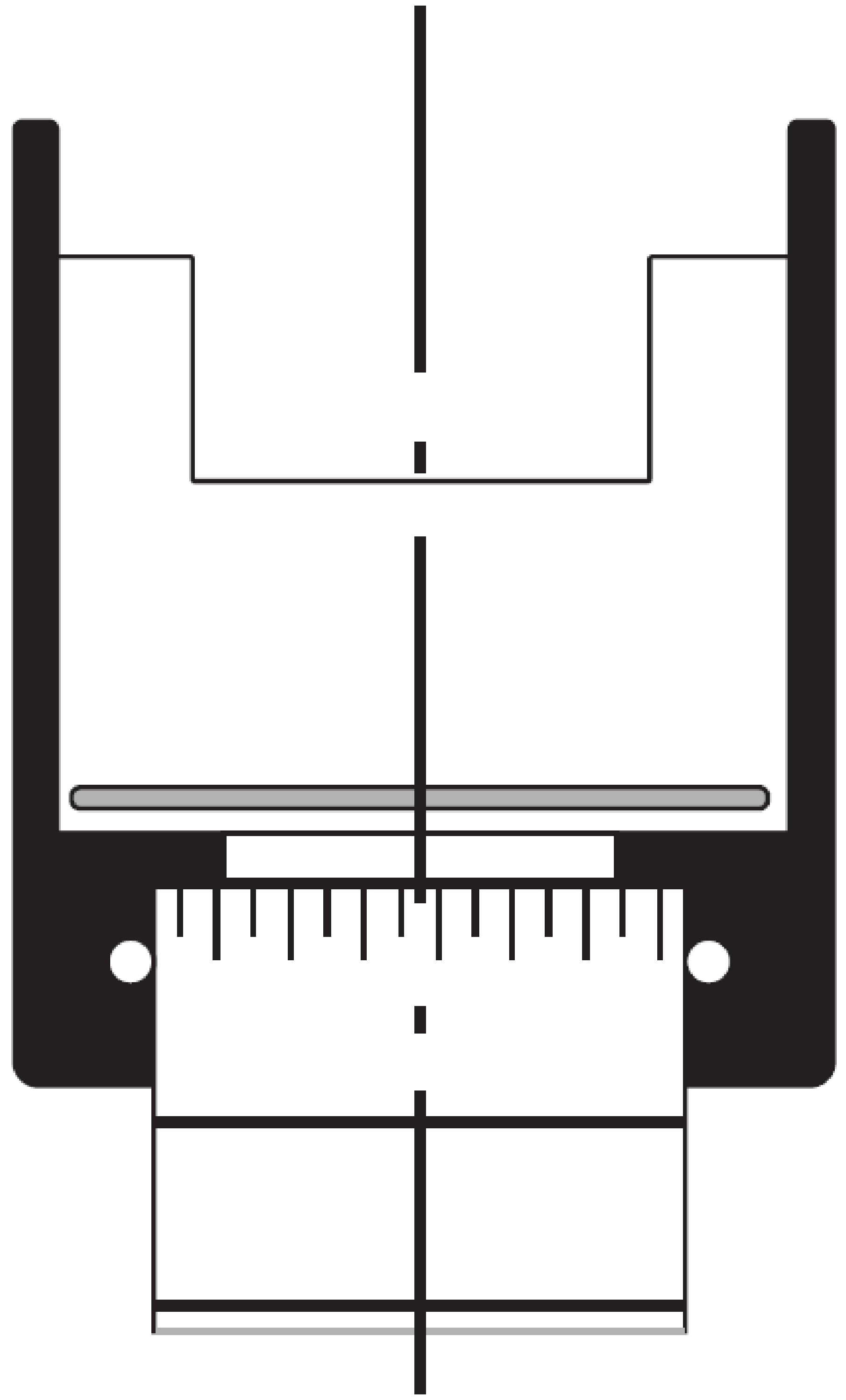
- Step 2
  - Turn off sound source
  - Apply insert voltage V_{IV}' in series with microphone and measure V_{IV}
  - Measure preamp output V_{OV}
  - Adjust V_{IV}' so that V_{OV} = V_P. This implies that V_{IV}.at this condition = Mic output voltage at the original P_0 from Step 1
  - OCS = $\frac{V_{IV}}{P_0}$ = Open Circuit Sensitivity



INSERT VOLTAGE TECHNIQUE

- OCS is a property of the microphone
  - Isolated from the preamplifier
- OCS is typically measured at a fixed frequency of the sound source
  - (the reference frequency)
- OCS can be expressed in dB or base units
  - $20 \times log_{10}\left[\frac{V_{IV}/_{P_0}(\frac{milliVolts}{Pascal})}{1000\ milliVolts/_{Pascal}}\right]$

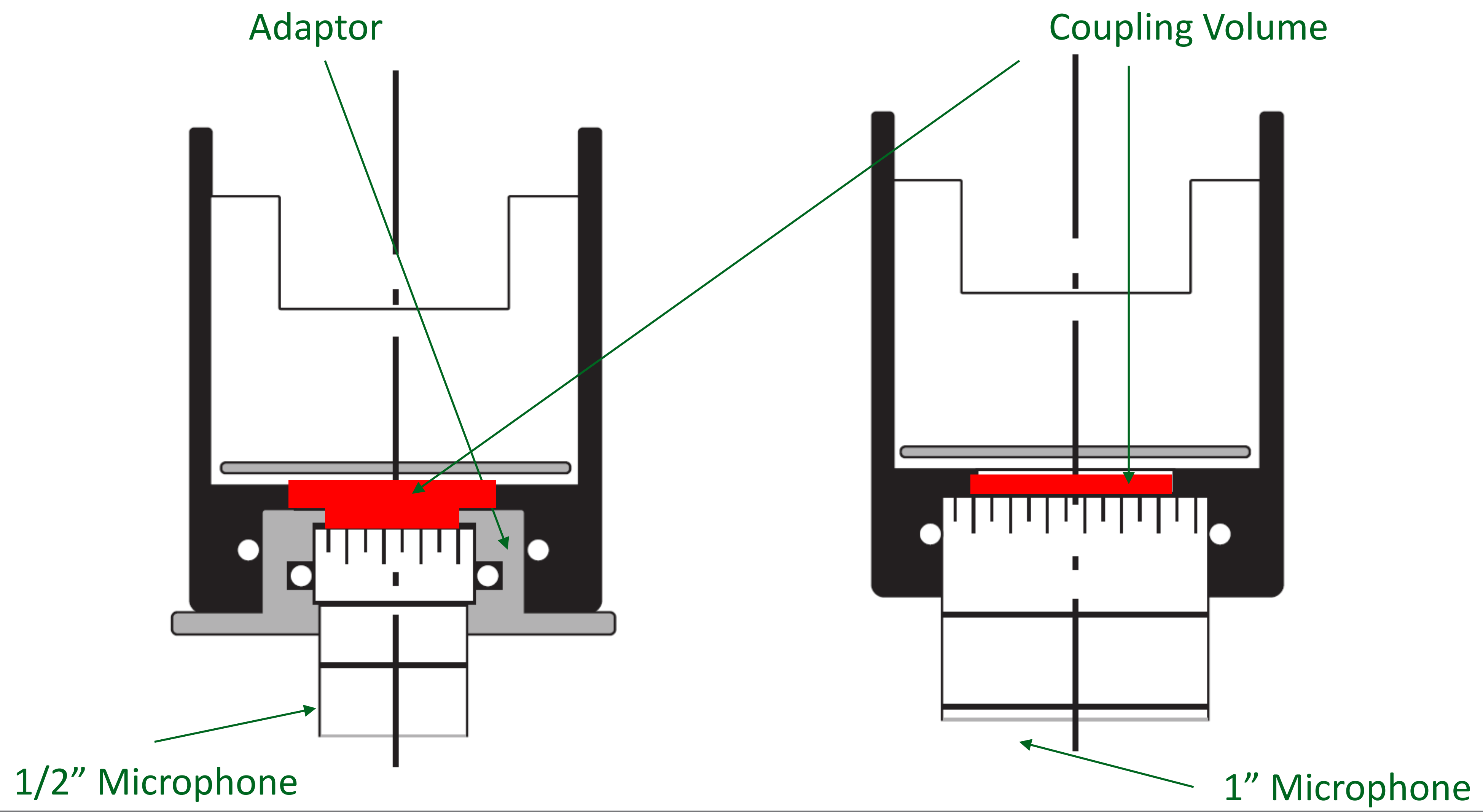
- Broadband frequency response is measured using an electrostatic actuator



NOTES ABOUT PISTONPHONES

- Consistent coupling volume is required
  - Adaptor design
- Volume Correction factor
  - Must be applied
  - Varies with microphone size
  - Varies with/without protection grid
- Sensitivity to atmospheric pressure
  - Supplied with a calibrated barometer
  - Barometer provide correction in dB

- Sensitivity to alignment
  - Changes volume
- Sound Calibrators
  - Different than pistophone
  - Loudspeaker with current feedback
  - None of the issues above

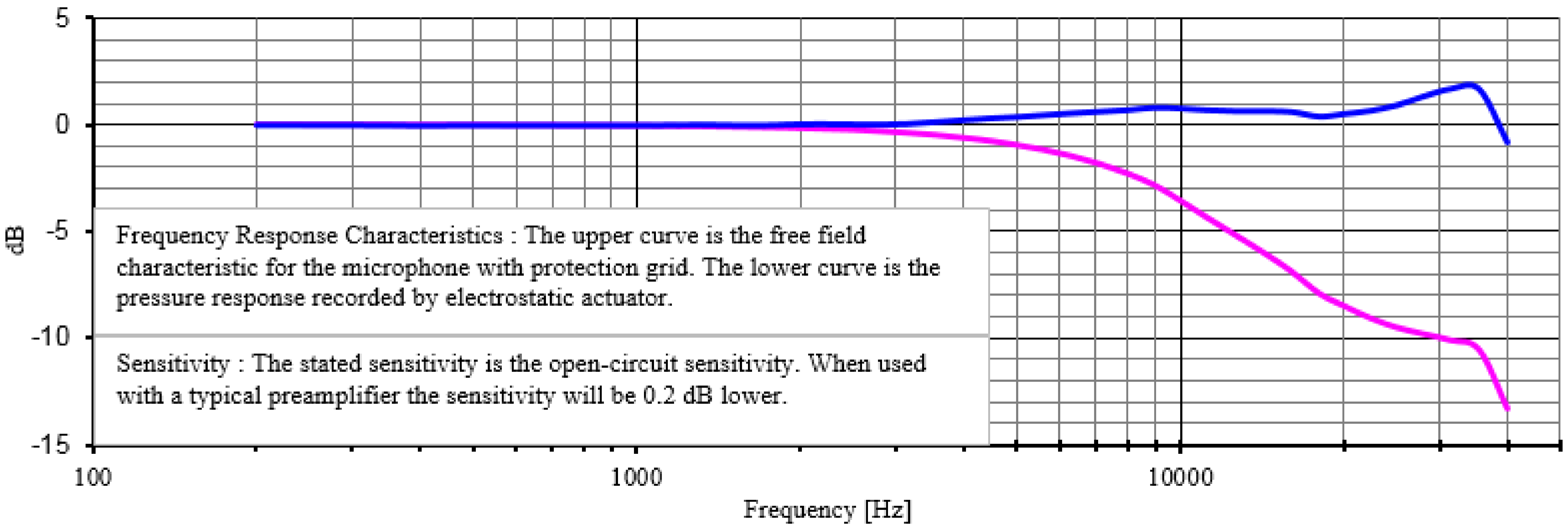


ELECTROSTATIC ACTUATOR METHOD

- Electrostatic actuators are described in IEC 61094-6
- The actuator is a rigid, electrically conductive plate
  - Placed close to and parallel to the microphone diaphragm
  - Holes in actuator reduce radiation impedance
- High impedance AC electrical voltages are applied to this capacitor to create a force on the diaphragm
- AC electrical voltages are relatively easily controlled over a wide frequency range

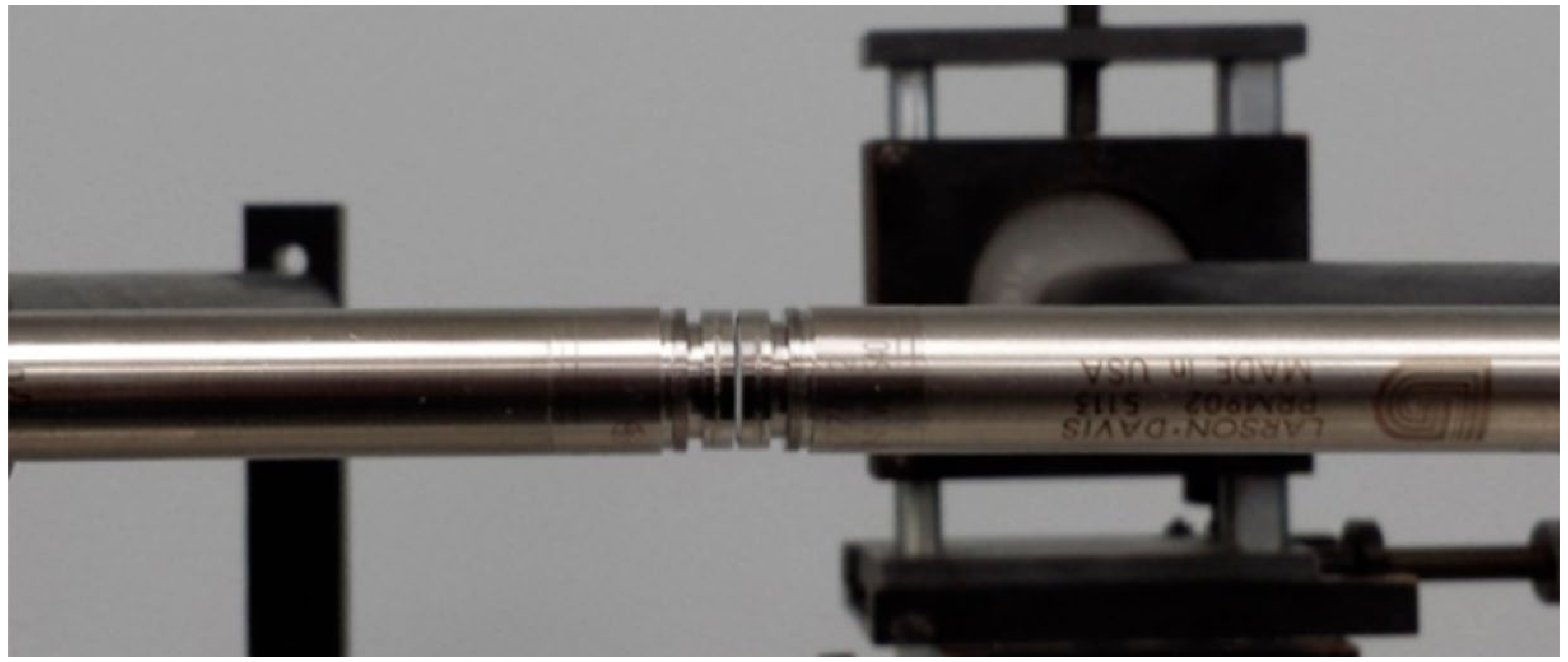
ELECTROSTATIC ACTUATOR METHOD

- The AC voltage is applied using stepped sine excitation
- The microphone output is measured at each frequency
- The result is an electrostatic actuator frequency response spectrum
  - Free field, random incidence, and pressure microphones are ‘corrected’ based on model with numbers determined through manufacturer testing



MICROPHONE COMPARISON METHOD

- Acoustic field is applied using stepped sine excitation
- Test microphone is mounted face to face with a reference microphone
- Each microphone output is measured at each frequency
- The result is a pressure response



MICROPHONE COMPARISON METHOD

- M_{Test} sensitivity of the test microphone, in ${}^{mV}/_{Pa}$
- M_{Ref} sensitivity of the reference microphone, in ${}^{mV}/_{Pa}$
- R_V ratio of the voltage output of the test microphone to the voltage output of the reference microphone
- R_P ratio of the sound pressure on the test microphone to the sound pressure on the reference microphone

- $C_{F/_P}$ field correction value referenced to the pressure response for the test microphone.
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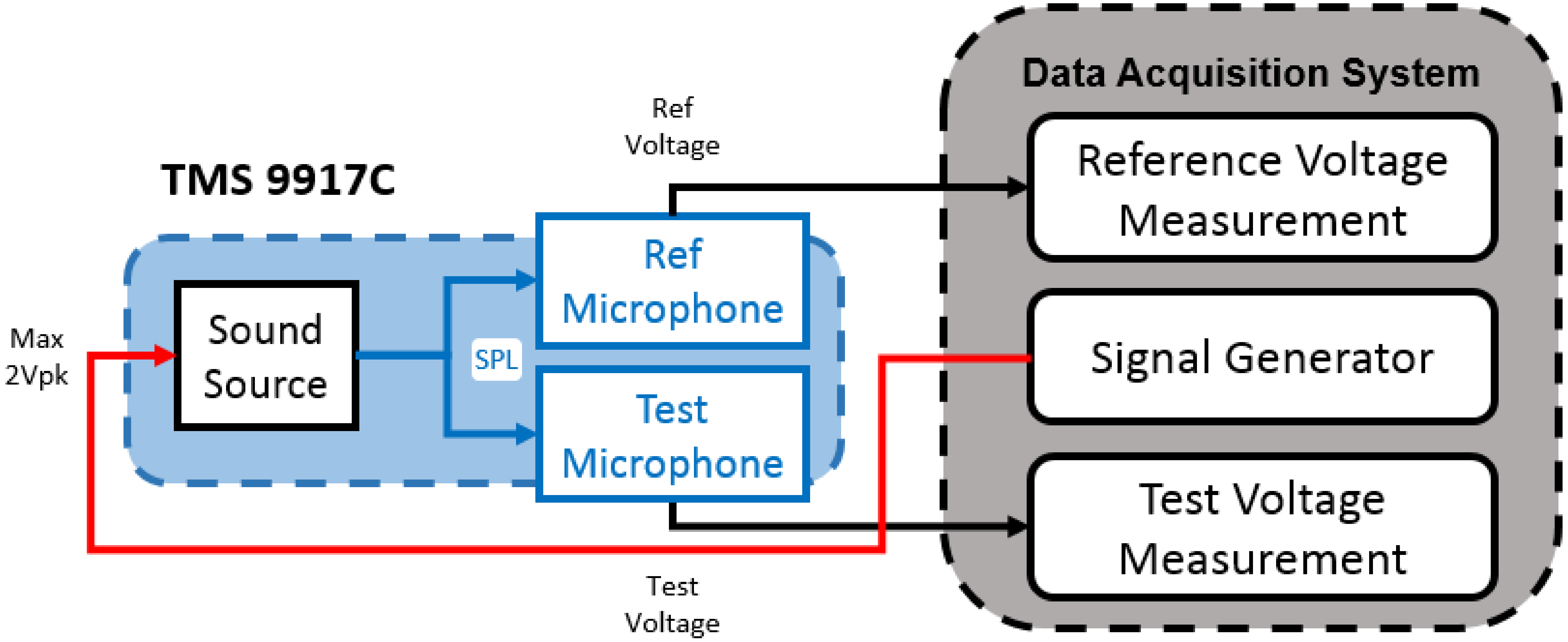
$$M_{Test} = M_{Ref} \times \frac{R_V}{R_P} \times C_{F/_P}$$

MICROPHONE COMPARISON METHOD

- Minimal Additional Instrumentation Required



MICROPHONE COMPARISON METHOD

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- M_{Test} sensitivity of the test microphone, in $^{mV}/_{Pa}$
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- R_V ratio of the voltage output of the test microphone to the voltage output of the reference microphone
- R_P ratio of the sound pressure on the test microphone to the sound pressure on the reference microphone
- $C_{F/P}$ field correction value referenced to the pressure response for the test microphone.

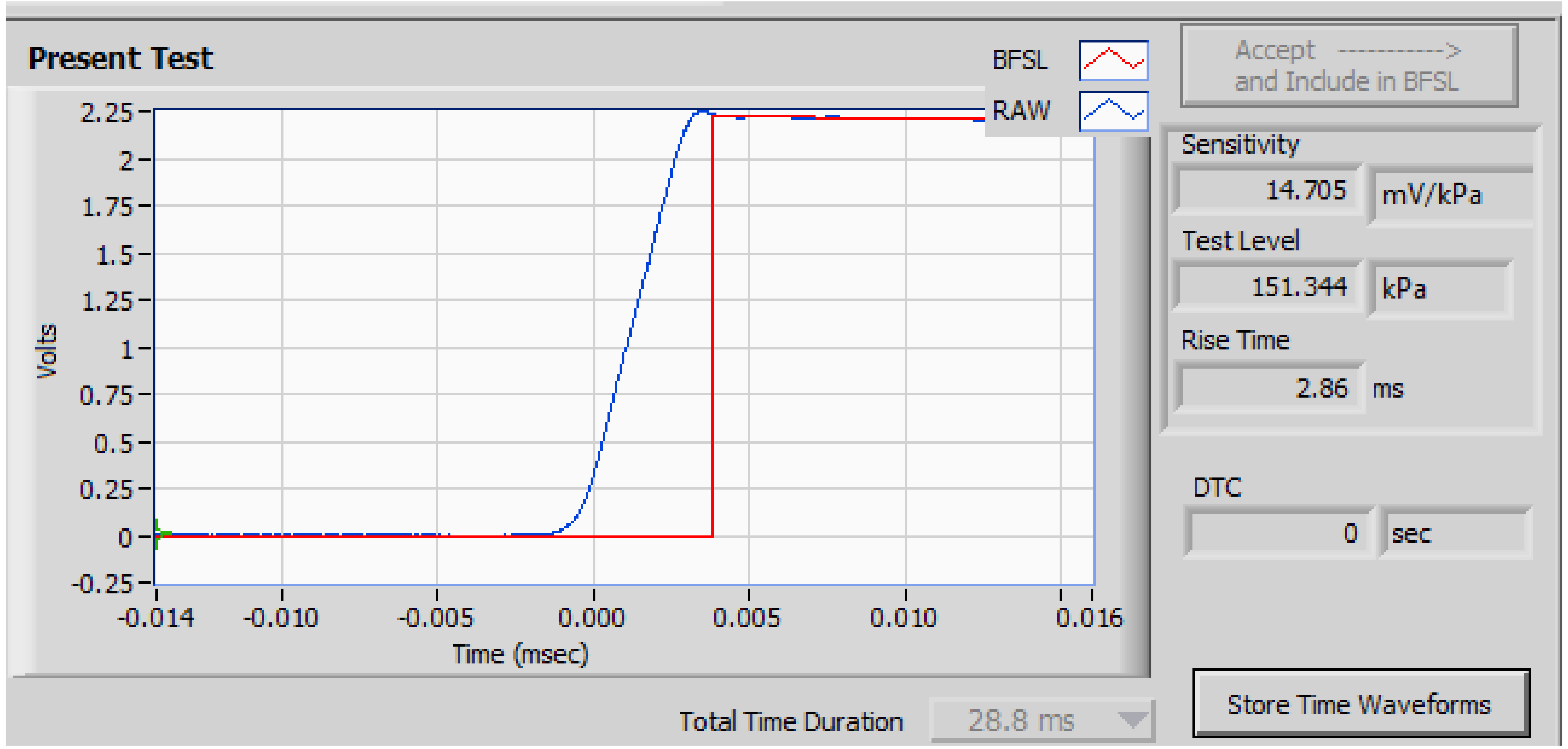
PRESSURE SENSOR CALIBRATION

- 2 Methods
  - Step Method
  - Impulse Method

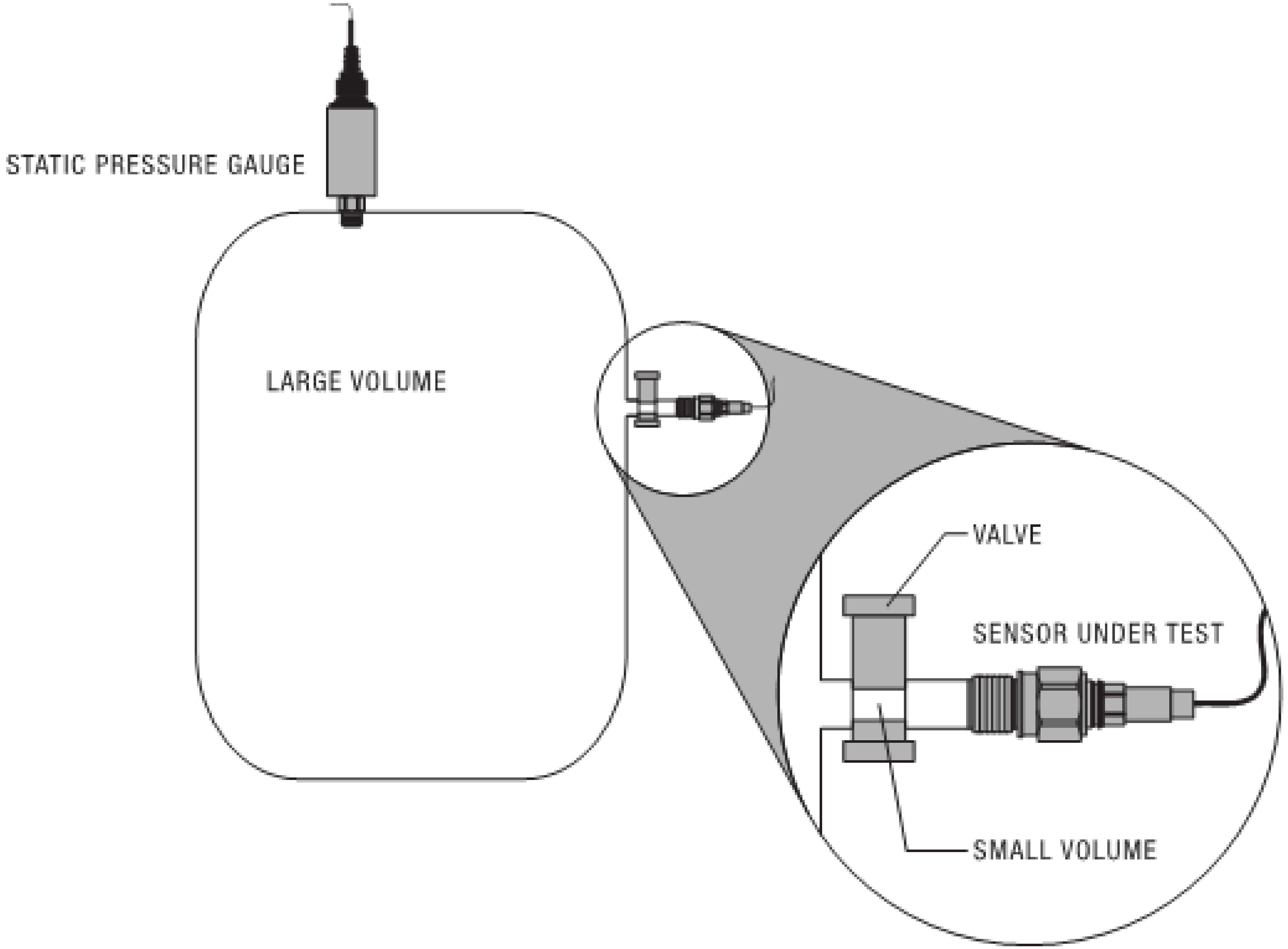
CALIBRATION – STEP METHOD

- Quick rise in pressure is applied
- Dynamic calibration using a static reference

$$Sensitivity_{SUT} = \frac{Voltage\ Rise_{SUT}}{Reference\ Pressure}$$

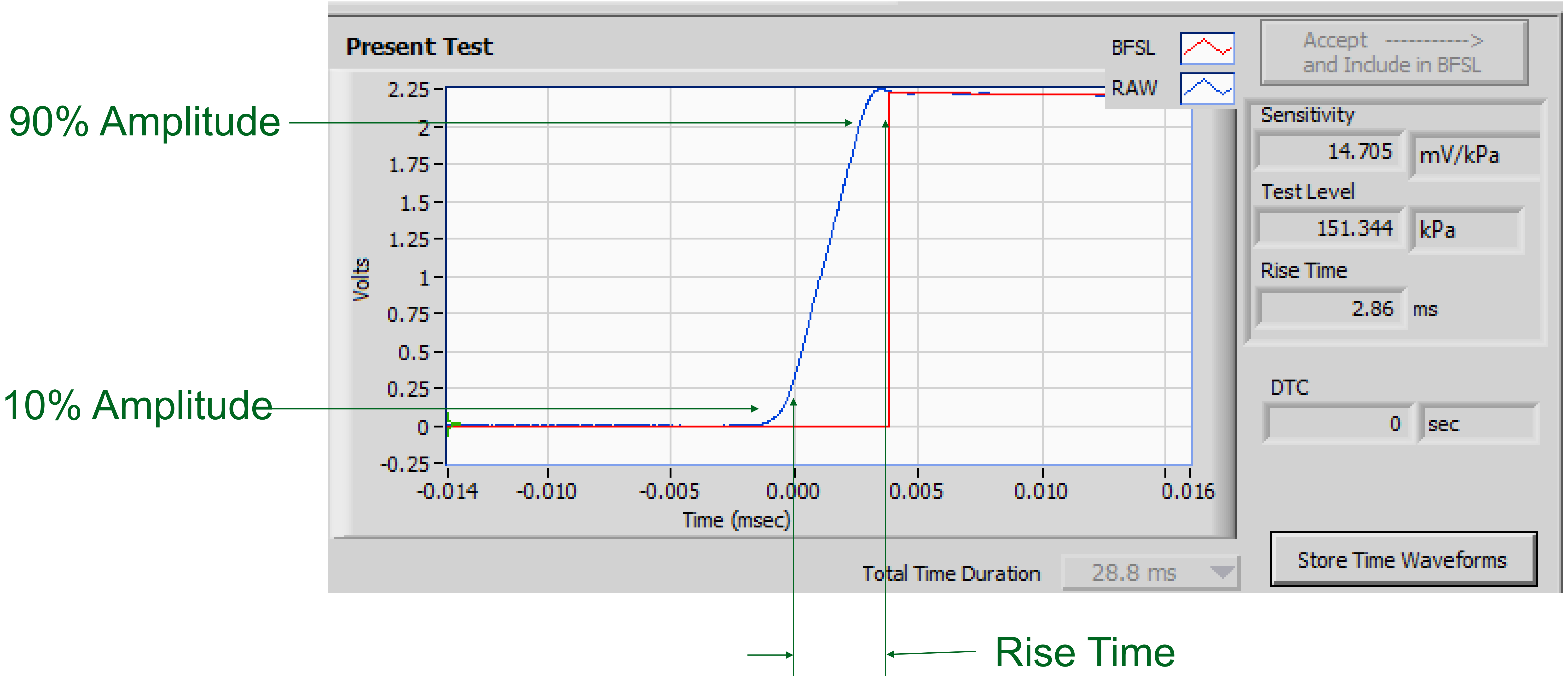


STEP METHOD

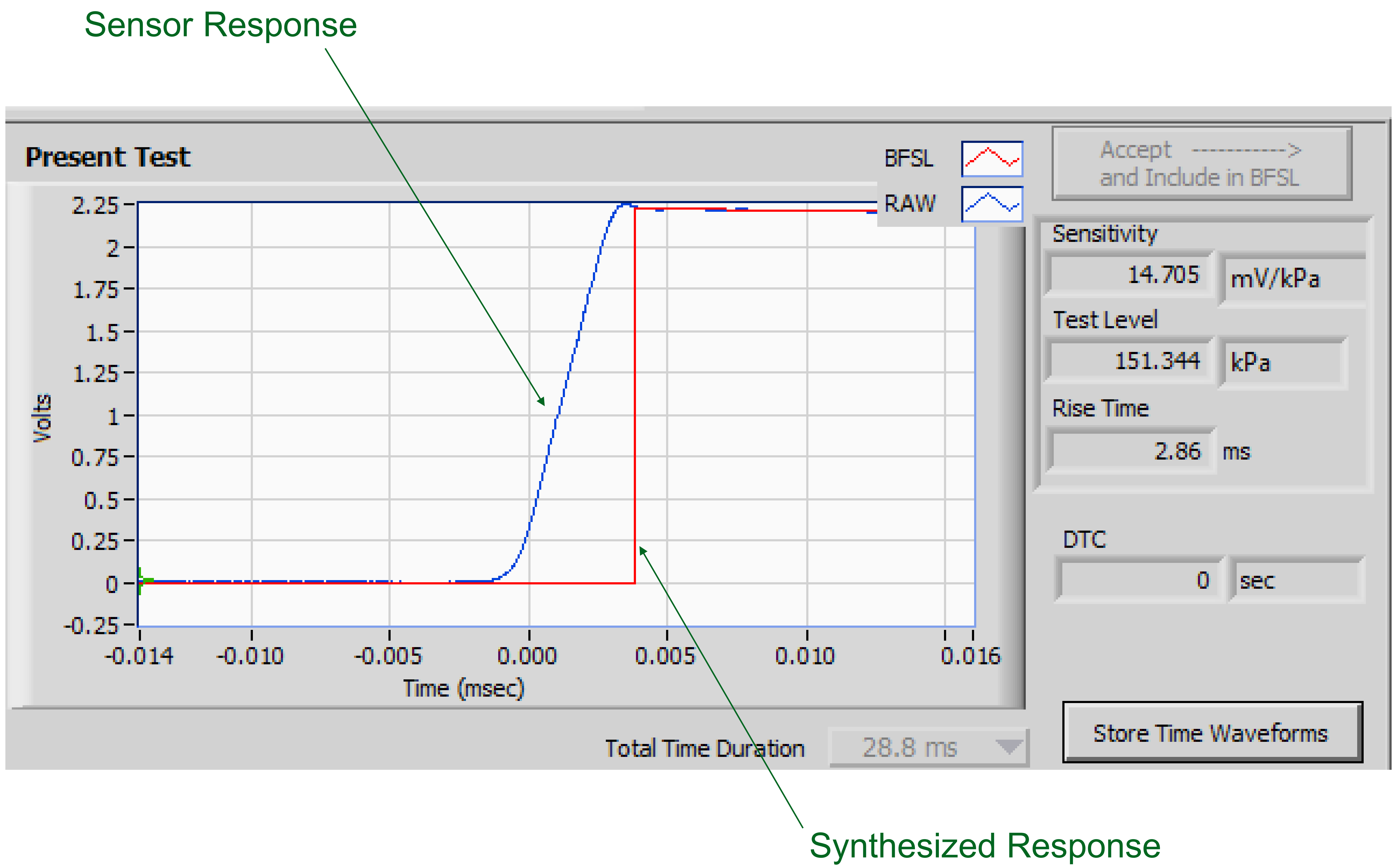


STATIC PRESSURE GAUGE
LARGE VOLUME
VALVE
SENSOR UNDER TEST
SMALL VOLUME

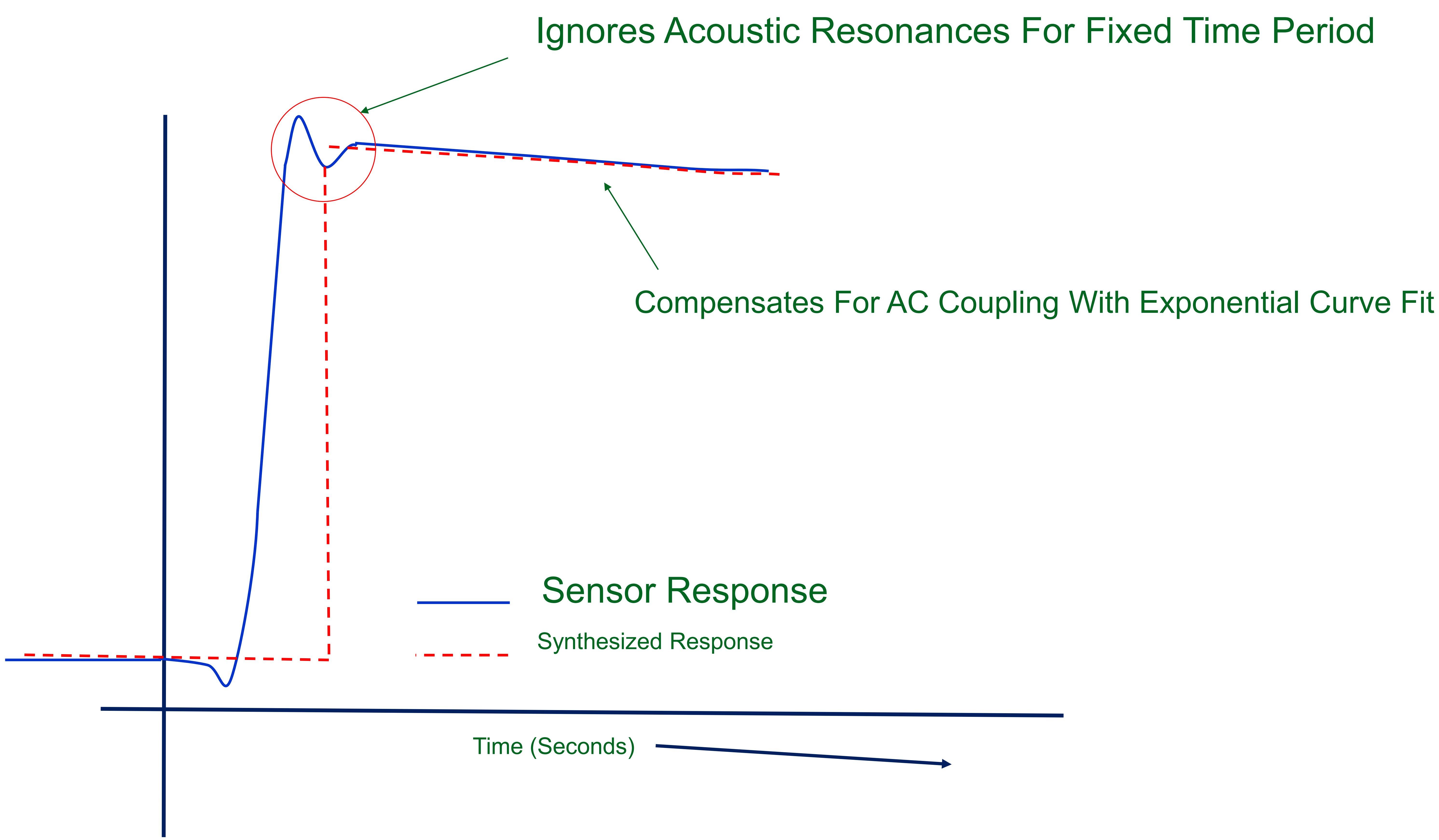
RISE TIME MEASUREMENT



'STEP' DATA ACQUISITION SOFTWARE (K9903C, K9907C)



SYNTHESIZED RESPONSE ALGORITHM

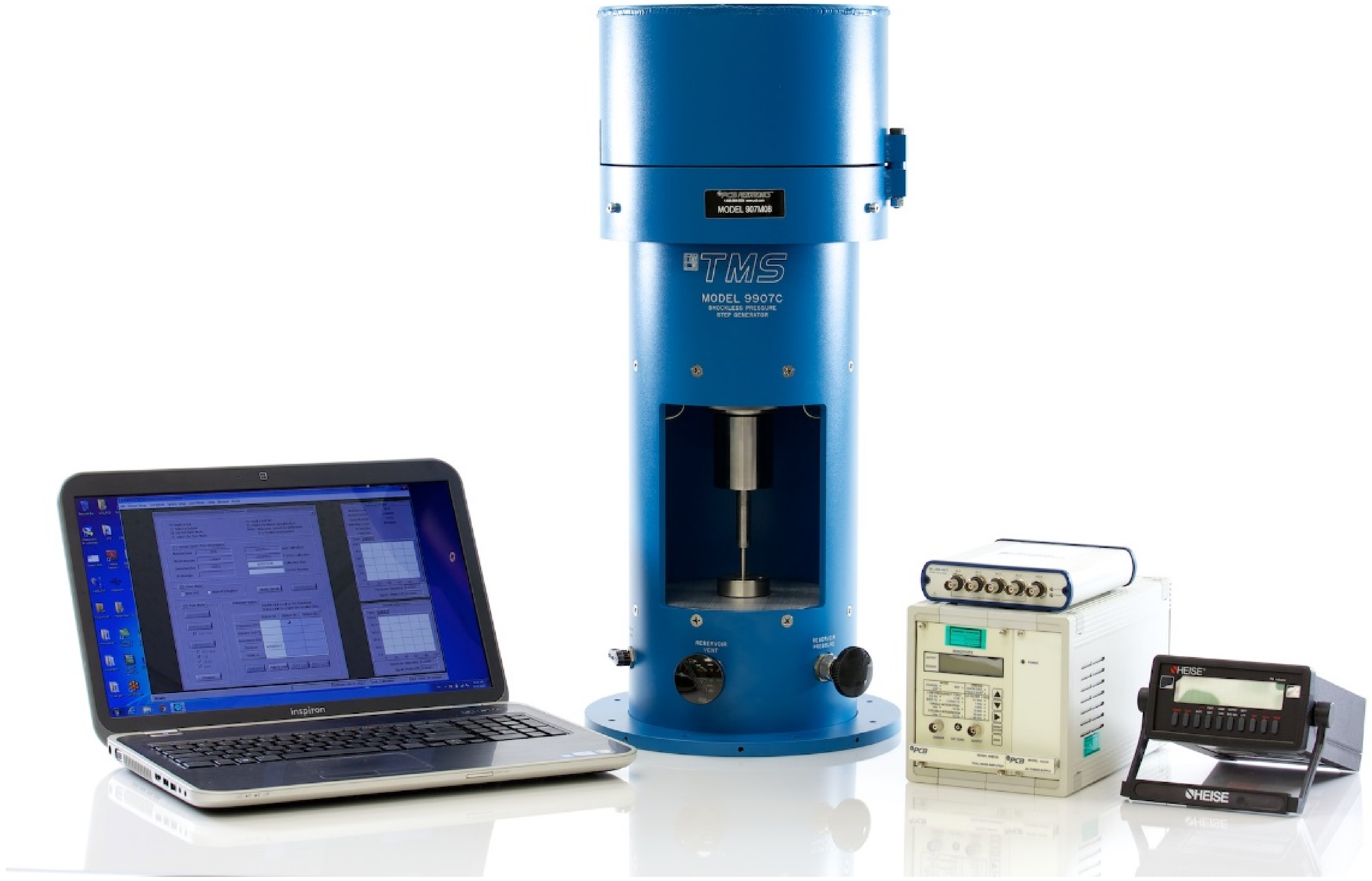


STEP METHOD

- K9903C
- Max Pressure = 150 psi
- ‘Step’ Input
- Pneumatic Media
- 3 to 5 ms rise time

STEP METHOD

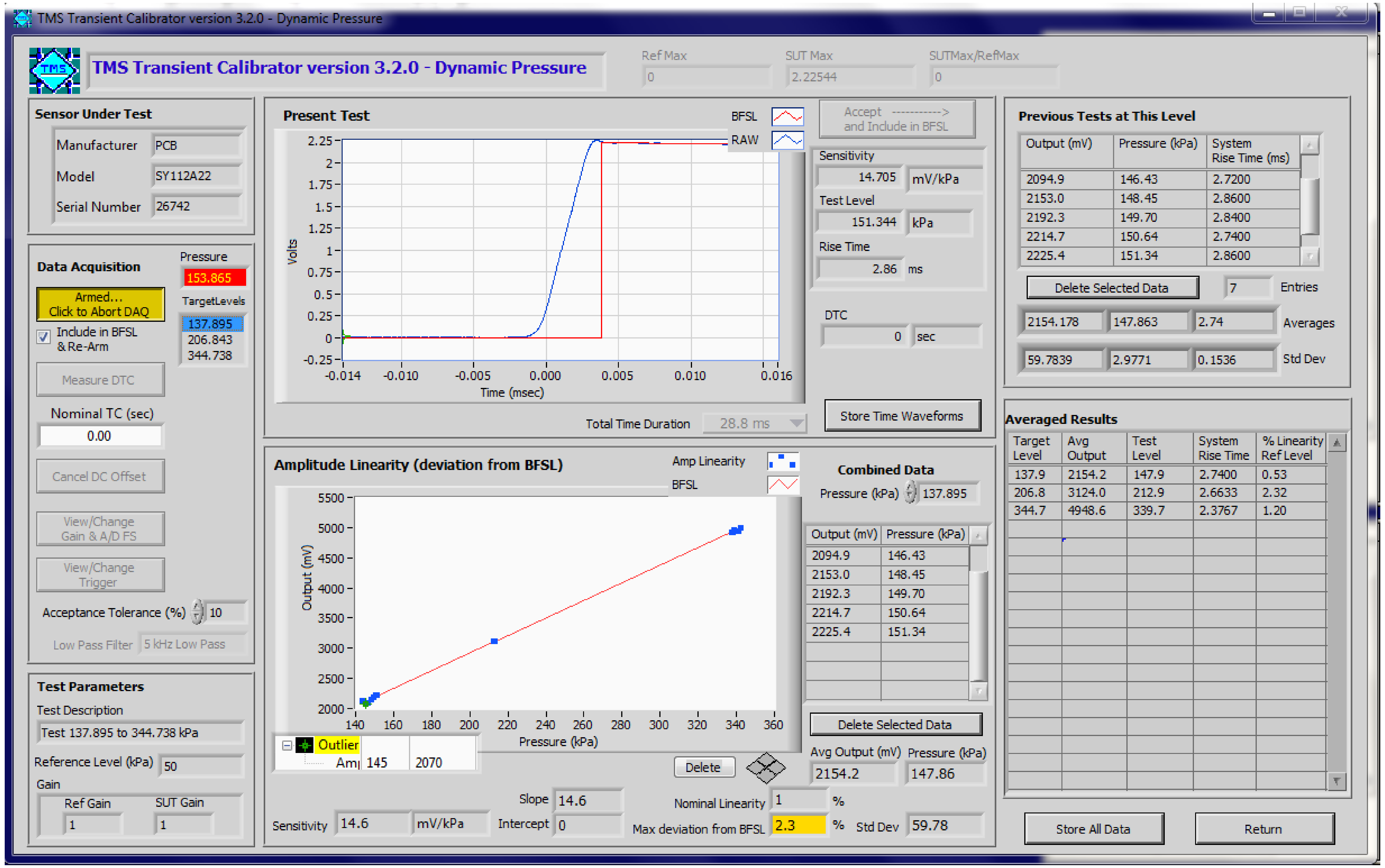
- K9907C
- Max Pressure = 1000 psi
- ‘Step’ Input
- Helium Gas
- 30 to 50 μsec rise time
- Fast acting poppet valve



STEP METHOD

- K9905D
- Max Pressure = 80 kpsi
- ‘Step’ Input
- Silicon Oil Media

‘STEP’ DATA ACQUISITION SOFTWARE (K9903C, K9907C, K9905D)



MTS SENSORS

PCB PIEZOTRONICS
MTS SYSTEMS CORPORATION

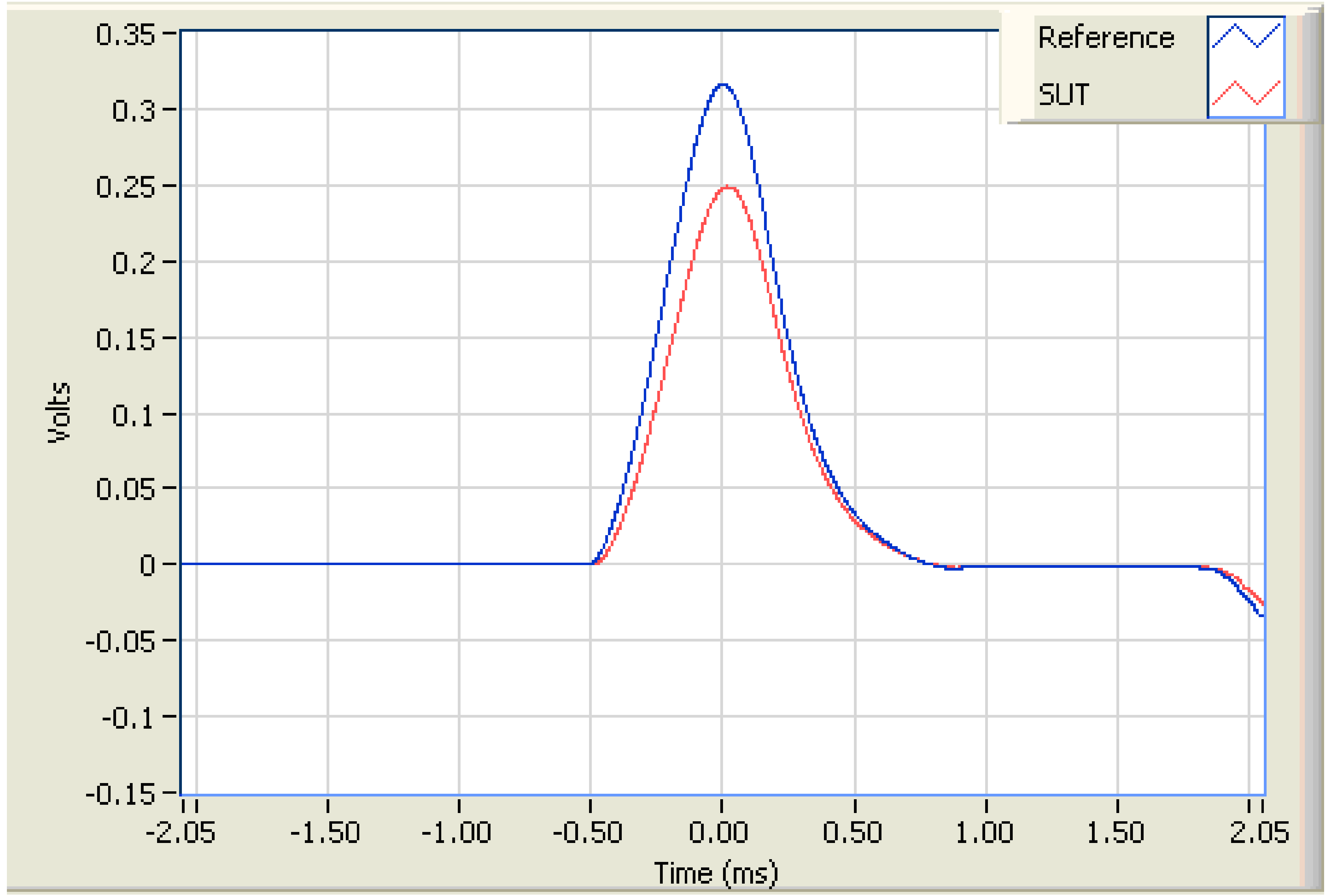
be
certain

CALIBRATION – IMPULSE METHOD

- Quick rise and fall in pressure
- Dynamic calibration using a piezoelectric reference
- Comparison calculation
- Traceability through static methods

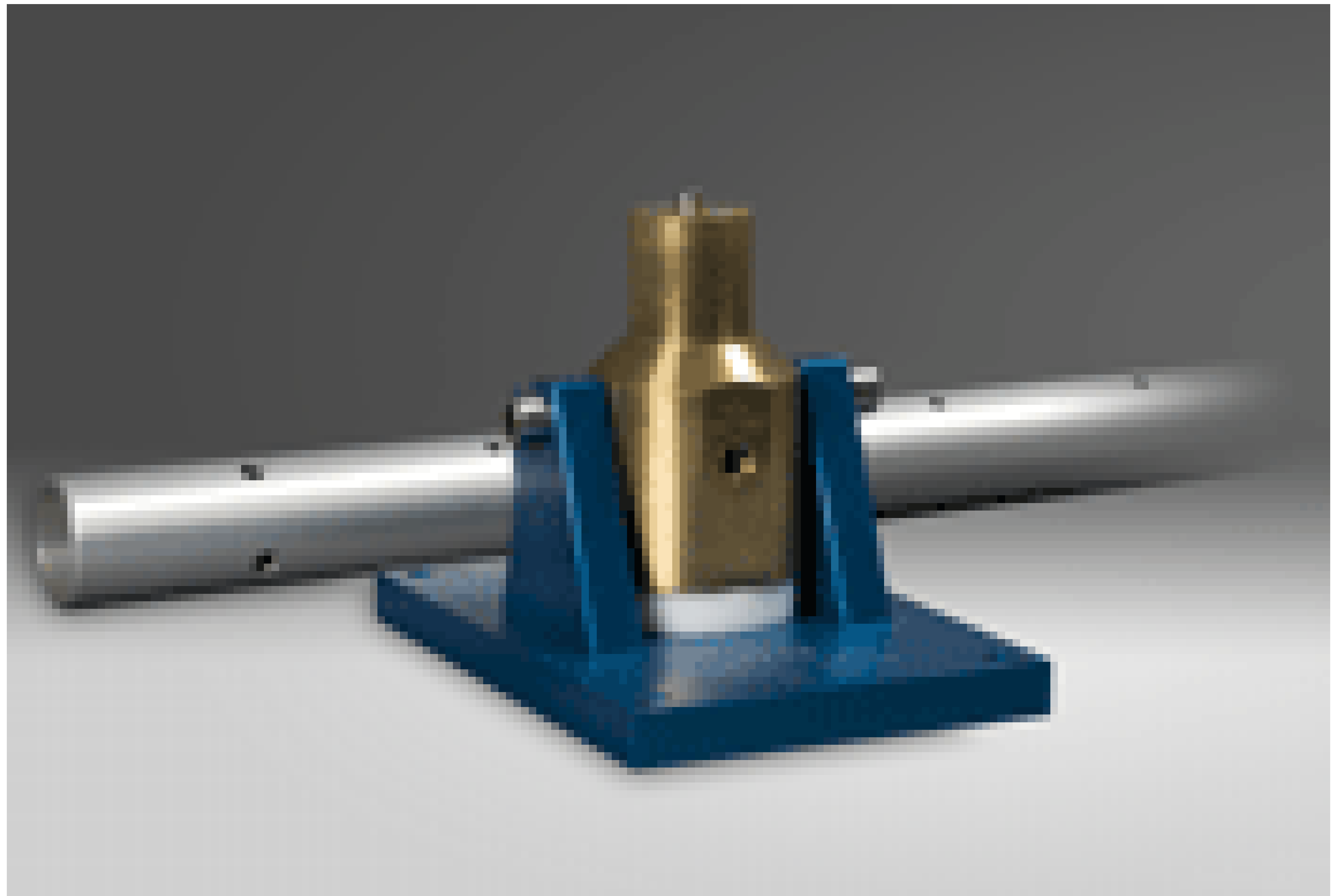
$$\text{Sensitivity}_{\text{SUT}} = \frac{\text{Voltage}_{\text{SUT}}}{\text{Voltage}_{\text{Ref}}} \times \text{Sensitivity}_{\text{Ref}}$$

Figure 5, Calculating sensitivity for the impulse calibration input.

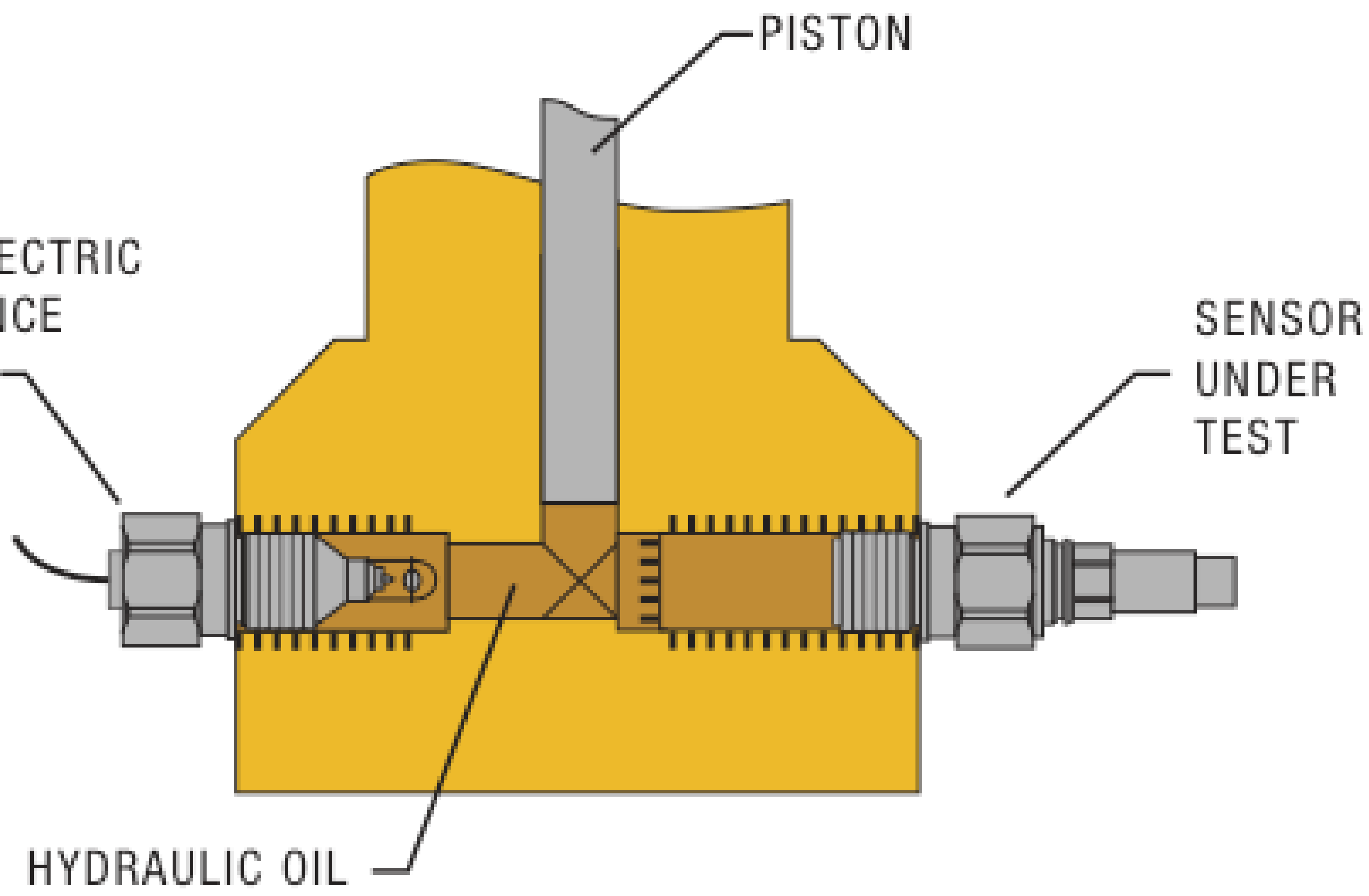


IMPULSE METHOD

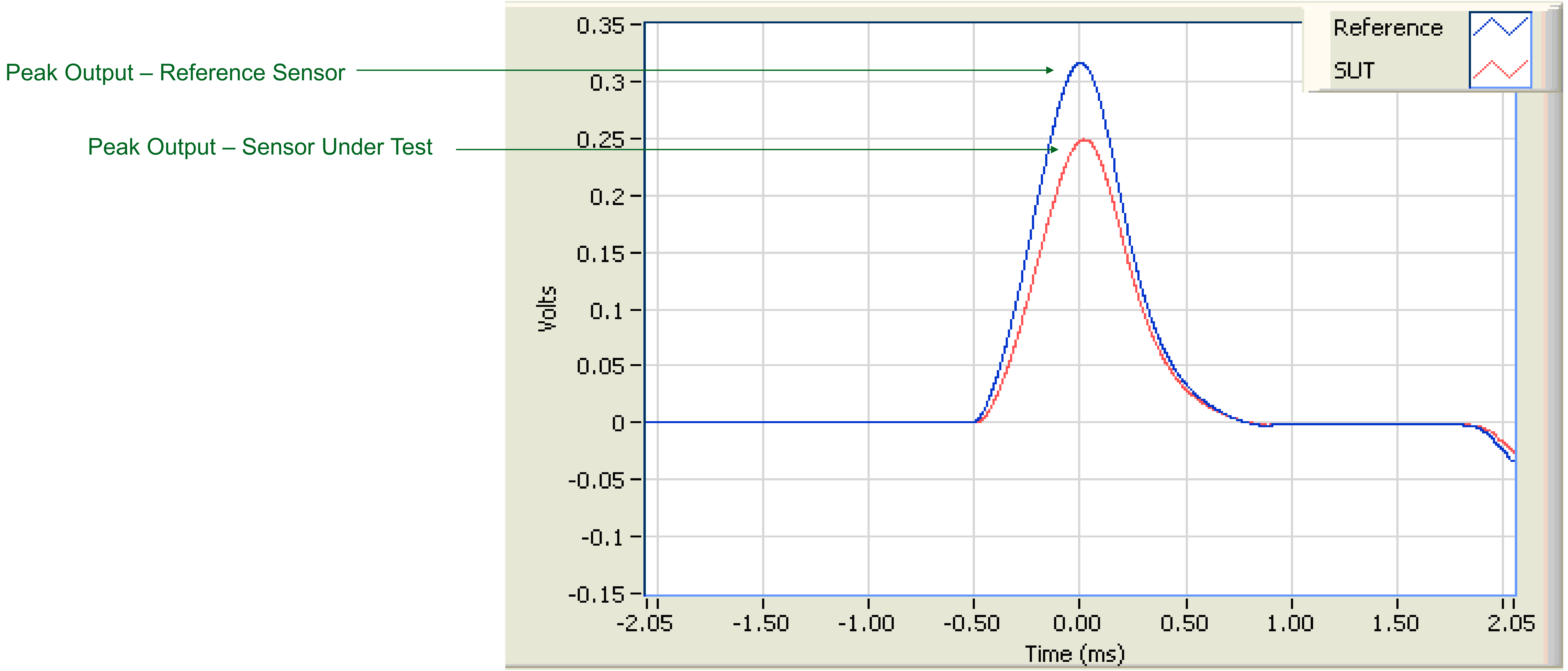
- Max Pressure = 15 ksi
- Impulse (Hammer) Input
- Silicon Oil Media
- Dropped Masses



IMPULSE METHOD

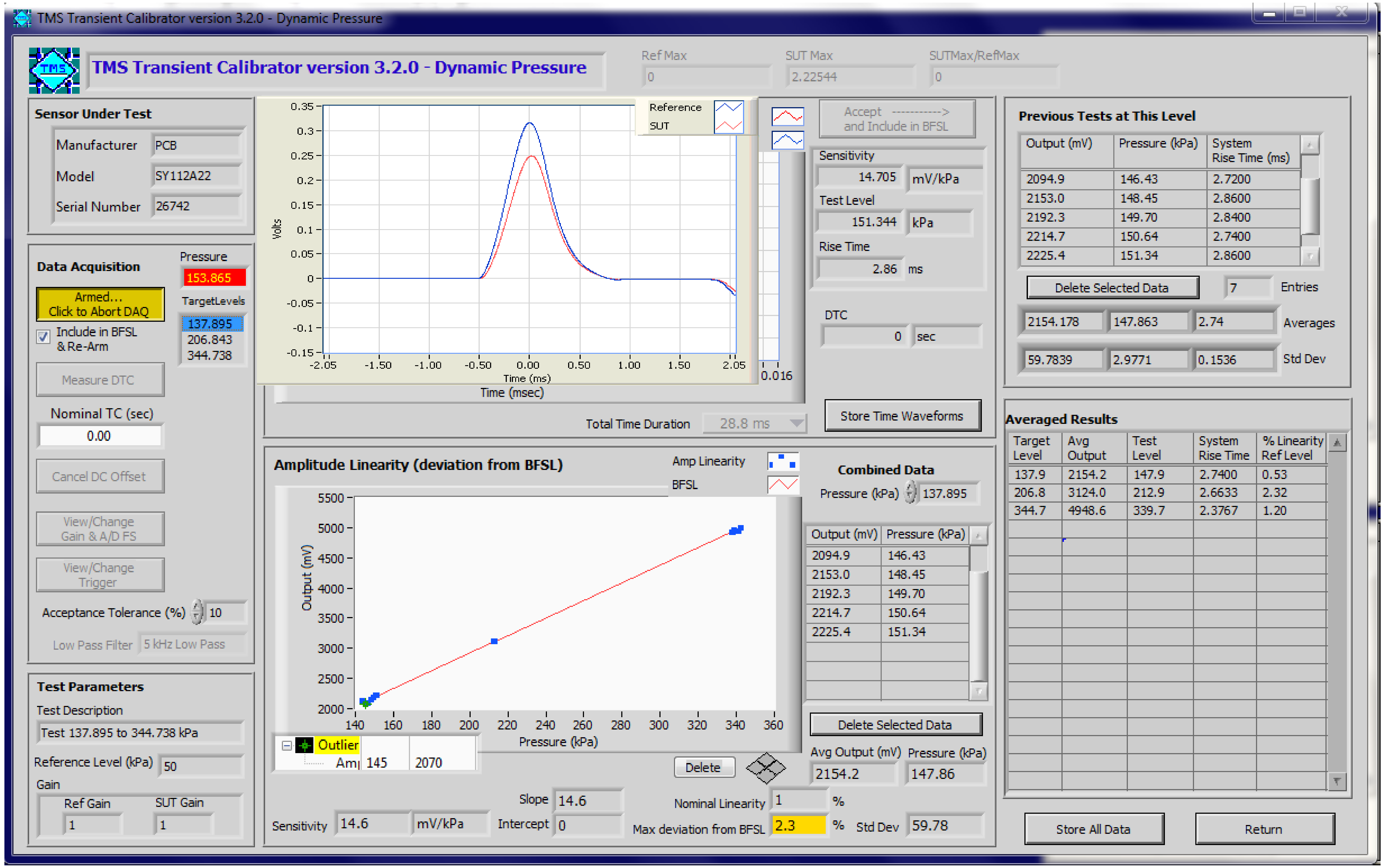


IMPULSE DATA ACQUISITION SOFTWARE



$$Sens_{SUT} = Sens_{Ref} \frac{Voltage_{SUT}}{Voltage_{Reference}}$$

IMPULSE DATA ACQUISITION SOFTWARE



MTS SENSORS

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QUESTIONS?