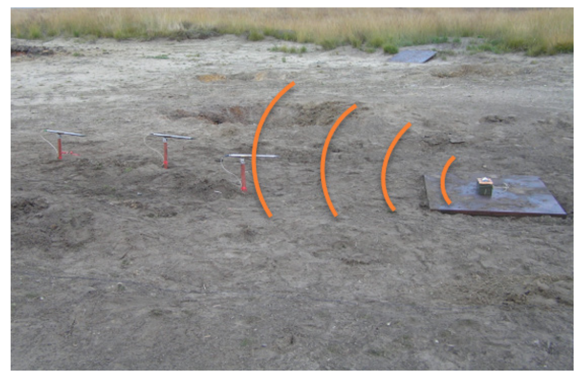
# PERFORMANCE CHARACTERISTICS

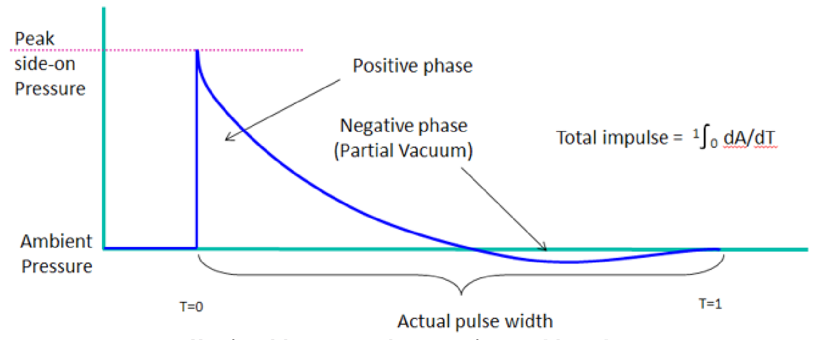
## OF PIEZOELECTRIC & PIEZORESISTIVE PRESSURE SENSORS FOR BLAST

**Presented by Carmine Salzano, PCB Piezotronics, Inc.**

## Shock Waves[1]

- Static overpressure is the transient differential pressure in the air blast relative to the existing ambient pressure just before shock wave arrival
- Measured using a flush surface mount pressure sensor on the ground, or a pencil probe in the free field






**Net (positive + negative areas) = total impulse**
**$I = \int (p(t))dt$ expressed as psi*mili seconds**

## Pressure Sensor Location

**In the free field, sensors should be located:**

- Perpendicular to the incoming shock wave
- Away from disturbances in the blast front (e.g. fragmentation, reflecting surfaces)

## Two Measurement Techniques

**Quartz ICP® Piezoelectric Pressure Sensors**

- High stiffness for fast rise time
- ICP® output for good signal quality and resolution to 0.7 mili-psi (5 Pa)
- See models below: PCB 137B, 102B, 113B

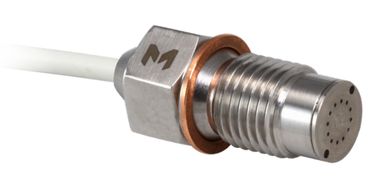
**Series 137B pencil probe**

**Series 102B**

**Series 113B**

**Piezoresistive Silicon Pressure Sensors**

- Fast response time to measure blast wave
- DC coupled with absolute pressure measurement capability
- 8530 are supplied with 4-pin electric connector for improved durability
- See models below: Endevco 8511AM8, 8530BM37, 8530CM37



**8511AM8**

**8530BM37 & 8530BC37**

## PR and ICP® Comparison

**Dynamic Range of a 50 psi sensor**

- ICP® is 5000 mV FSO (ICP 113B28)
- PR is 225 mV FSO (MEMS 8510C-50)

**Durability**

- ICP® is hermetic with 20x over-range
- PR is epoxy sealed with 5x over-range

**Static Accuracy**

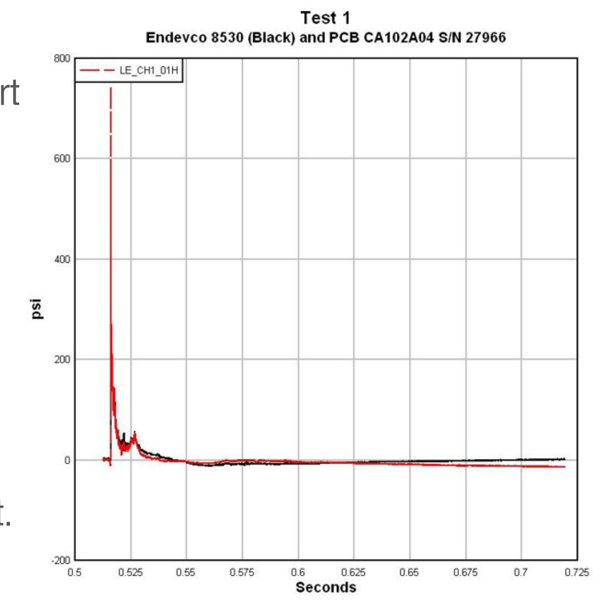
- ICP® is AC coupled, but long enough for shock wave impulse measurement
- PR is DC coupled, better for deflagration or cook-off testing

## Transient Thermal Effects

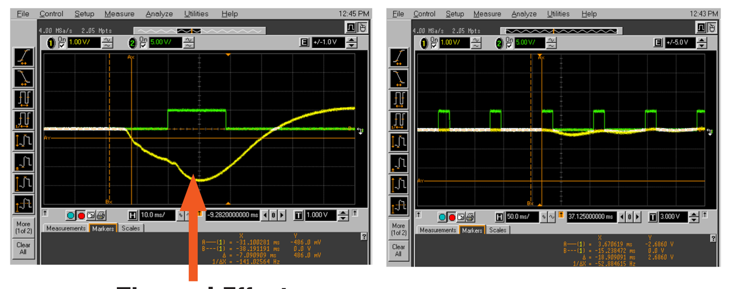
**All pressure transducers respond to thermal transients**

- PR (MEMS) pressure transducers respond to thermal transients with non-symmetric changes in bridge resistance
  - Even though small, resistors diffused in silicon don't see the same temperature at the same time
  - Individual changes in each resistor (thermoresistive effect) result in unbalancing the bridge
  - Bulk silicon MEMS pressure transducers also respond to light (photovoltaic and photoresistive effects)
  - Black grease and a screen placed over the diaphragm blocks and delays radiant and convective heat transfer
  - Thermal compensation resistors do not satisfy this function in a measurement environment containing thermal transients
  - Good data can be obtained but it is challenging to acquire
- ICP® pressure sensors also experience thermal shock. See discussion in next panel.

## Transient Shock Data Discussion[2]




- The ICP® and PR pressure sensor diaphragms were properly protected in chart 1 below, but there is still undershoot after the main impulse – is it bad data?
- Undershoot is adiabatic expansion (partial vacuum), i.e., real data after shock wave passes
- A heat flux experiment was performed on ICP® Model 113B28 100 mV/psi PE sensor. Output in yellow shows negative undershoot.
- Transducer exposed to 4.77 BTU/ft²sec heat flux for 18.72ms
- -2.5V output corresponds to 42% of full scale range
- A second experiment shows ICP® Model 113B28 PE sensor with black vinyl electrical tape exposed to 5.39 BTU/ft²sec heat flux for 18.8ms
- A maximum output of -229 mV was recorded, corresponding to only 3.9% of full-scale range



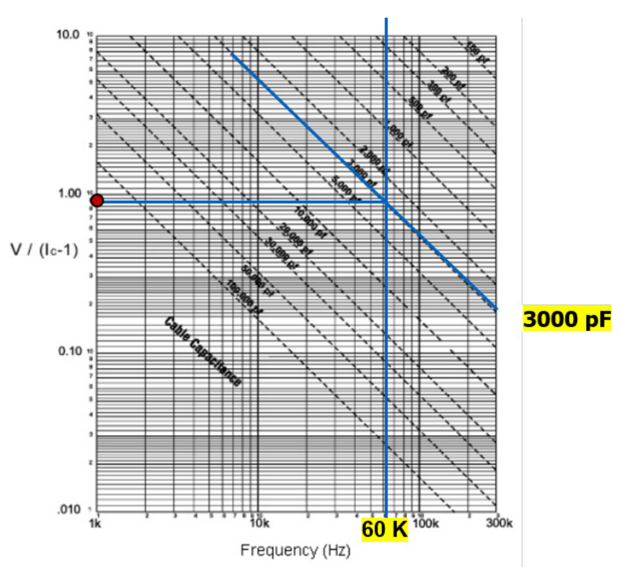
**Thermal Effect**

## Cable Frequency Limits[3][4]

- The RC time constant of the cable presents us with a first order low-pass filter

### Consider PCB ICP® Model 113B28 100 mV/psi, 50 psi range

**(Example $f_{max}$ we desire is 60 KHz, sample at 106 S/s so $f_{NY}$ is 500 KHz)**




For ICP® sensors, the cable capacitance can introduce slew rate limitations at high frequencies and high voltages.

**For 100 feet of coax at 30 pF/ft and 5V FS there is absolutely no cable limitation to be concerned with up to 60 KHz ($i_c$ = 6.5 mA)**

### Now consider Endevco 8510C-50 4.5 mV/psi, 50 psi range

**(Example $f_{max}$ we desire is 60 KHz, sample at 106 S/s so $f_{ny}$ is 500 KHz)**

For an RC circuit we have a time constant, τ = RC. The sensors -3dB freq in rad/sec is, ω-3dB = 1/τ = 2π f-3dB
If ωc is divided by 2π, the value of the filter cutoff frequency (fc) in Hz is [0.159/(RC)].

**Case 1:**
10 feet of cable at **15.9 pf/ft** = 159 pf (assume as shipped)
RC = 0.350 x $10^{-6}$ sec
$\omega_{-3db}$ = 2.86 x $10^6$ rad/sec
$f_{-3db}$ = 455 KHz
.54 x $f_{-3db}$ = 246 KHz **(<< 1 dB attenuated at 60 KHz)**
Attenuation at $f_{NY}$ = 33%

Belden nonpaired #82418, 4-conductor cable

**Case 2:**
90 feet of additional cable spliced at **30 pF/ft** = 2859 pf total
RC = 6.29 x $10^{-6}$ sec
$\omega_{-3db}$ = 0.159 x $10^6$ rad/sec
$f_{-3db}$ = 25.3 KHz
.54 x $f_{-3db}$ = 13.6 KHz (so >> 1 dB; **[attenuation at 60 KHz is ~69%]**)
Attenuation at $f_{NY}$ = 95% (-26 dB)

## Summary

**Dynamic Range of a 50 psi sensor**

- ICP® is 5V FSO

**Durability**

- ICP® is hermetic with very high over-range

**Static Accuracy**

- PR is DC coupled and referenced either to atmospheric pressure or vacuum (absolute)

**Transient Thermal Effects**

- PR for durations longer than 20 mili-seconds
- ICP® for shock waves

**Cable Length Limits**

- ICP® with higher current
- PR with amplifier in-line

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References: (1) TN27 by Dr. Patrick L. Walter, Measuring Static Overpressures in Air Blast Environments (2) WP59 by Justin Barrow, Test Apparatus Design for Assessment of Techniques Used to Mitigate Thermal Transient Response of Blast Pressure Transducers (3) WP85 by Dr. Patrick L. Walter, MEMS Shock Accelerometer Signal Modification Attributable to the Electrical Impedance of Their Cables (4) PCB General Signal Conditioning Guide