RYERSON UNIVERSITY

Using Ultrasound to Probe the Electrokinetic Property of Soft Biological Tissues

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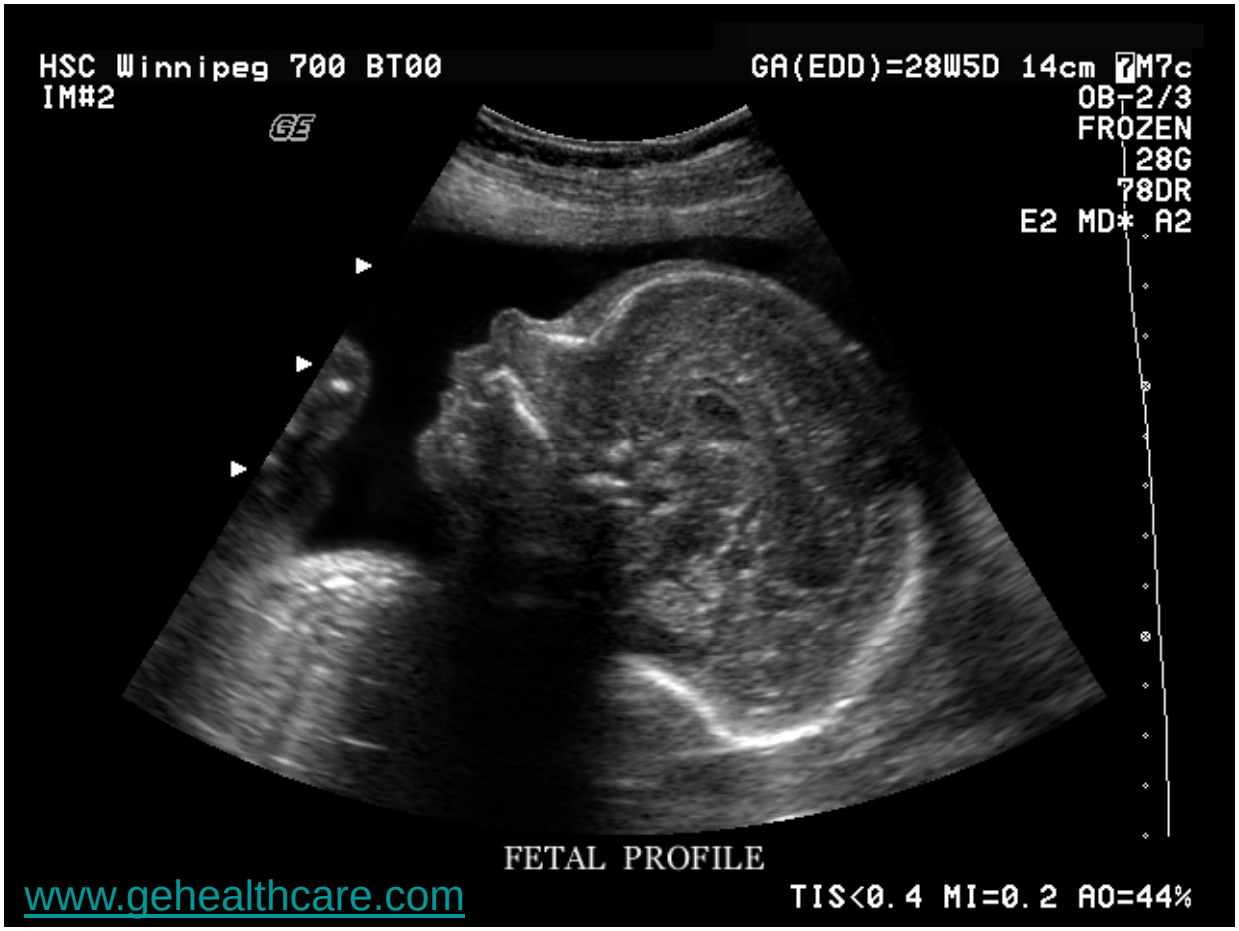
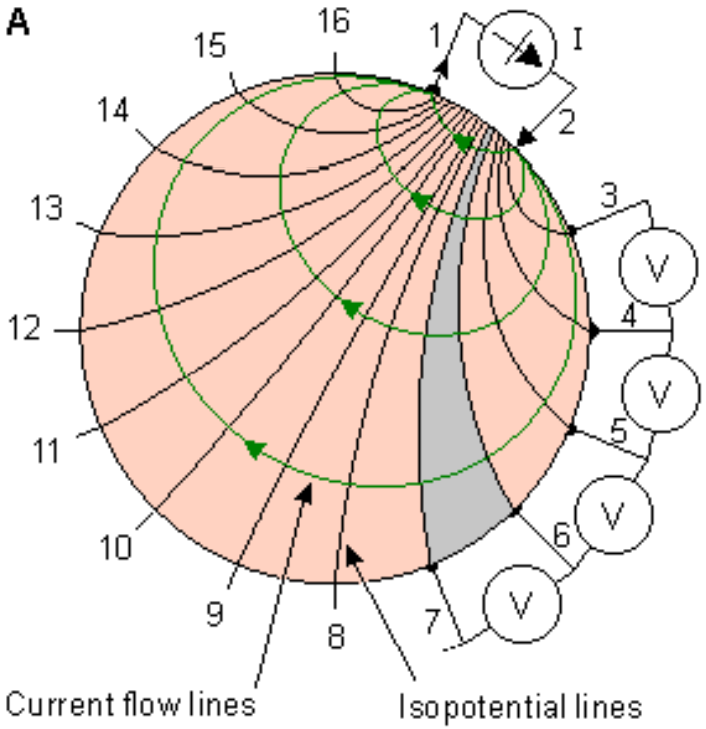
Ultrasound imaging



Limited Contrast
(Backscattering coefficient of tissues)

Good Spatial resolution
(scalable with imaging depth)

Principles of Electrical Impedance Tomography (EIT)



- Strength of EIT
  - Electrical conductivity and permittivity are correlated with the physiological and pathological status of tissues
  - Good temporal resolution

- Disadvantage:
  - Poor spatial resolution

Motivation

Electric field + Ultrasound

Good Contrast + High spatial resolution

Optical Imaging

Microwave Imaging

Electrical impedance tomography

Ultrasound Imaging

For example, photoacoustic tomography combines light with ultrasound to image the optical absorption at the spatial resolution of sonography.

Interaction between ultrasound and electric field

- Ultrasound induced by electric current in biological tissues
  - **Magnetoacoustic tomography with magnetic induction**
  - **Magnetoacoustic tomography (Hall effect imaging, Han Wen)**
- Ultrasound-induced electrical potential difference in biological tissues
  - **Magneto-acousto-electrical tomography**
  - **Ultrasound-modulated electric impedance tomography**
  - **Ultrasonic vibration potential in biological tissues**
- Using ultrasound to probe the electrokinetic property of soft biological tissues

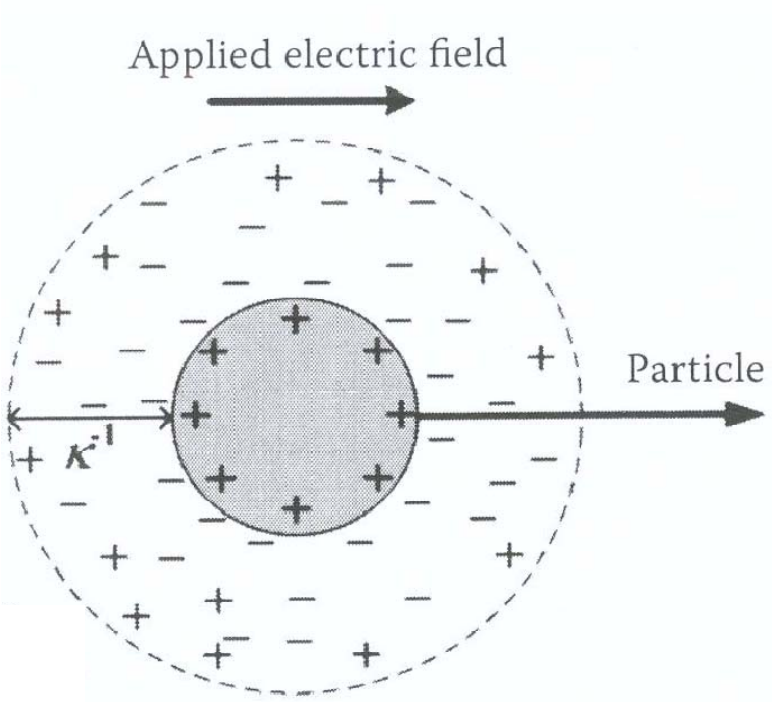
Electrokinetic Properties of Tissues: Fixed Charge Density

- There are fixed charges
  - on cell surfaces (proteins)
  - glycosaminoglycans (GAG) in extracellular matrix. GAGs are especially abundant in cartilage tissues and intervertebral discs (IVD).
- Fixed charge density depends on
  - Tissue composition
  - Tissue's pH value, which is related with the metabolism of the tissue.

Principle: Electrokinetic Effects in Tissues

There are **fixed charges** on cell surfaces (proteins) and in extracellular matrix due to GAG (glycosaminoglycans).

***Electrokinetic* phenomena** involve relative motion of charged surfaces and bulk solution.

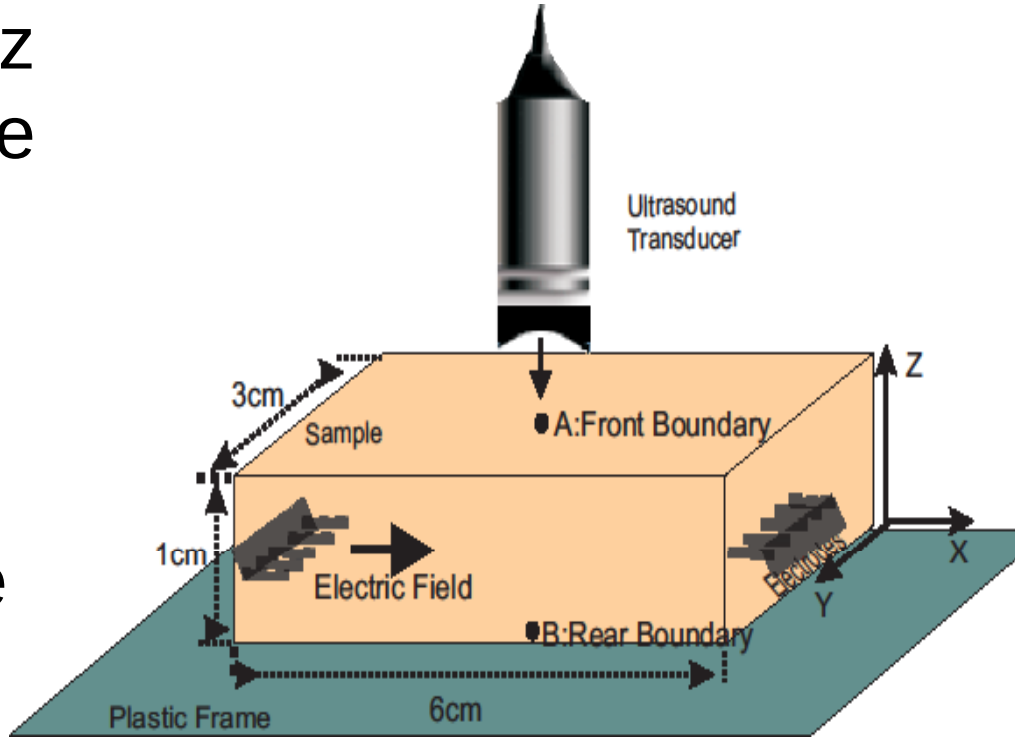


Electrophoresis : Motion of charged particles in solution due to electrical field.
Electroosmosis : Motion of solution under the influence of an electrical field.

Consequently, the local density and structure of the tissue in an electric field will change, which can be monitored by ultrasound.

Electric-field Induced Mechanic Changes in Tissues

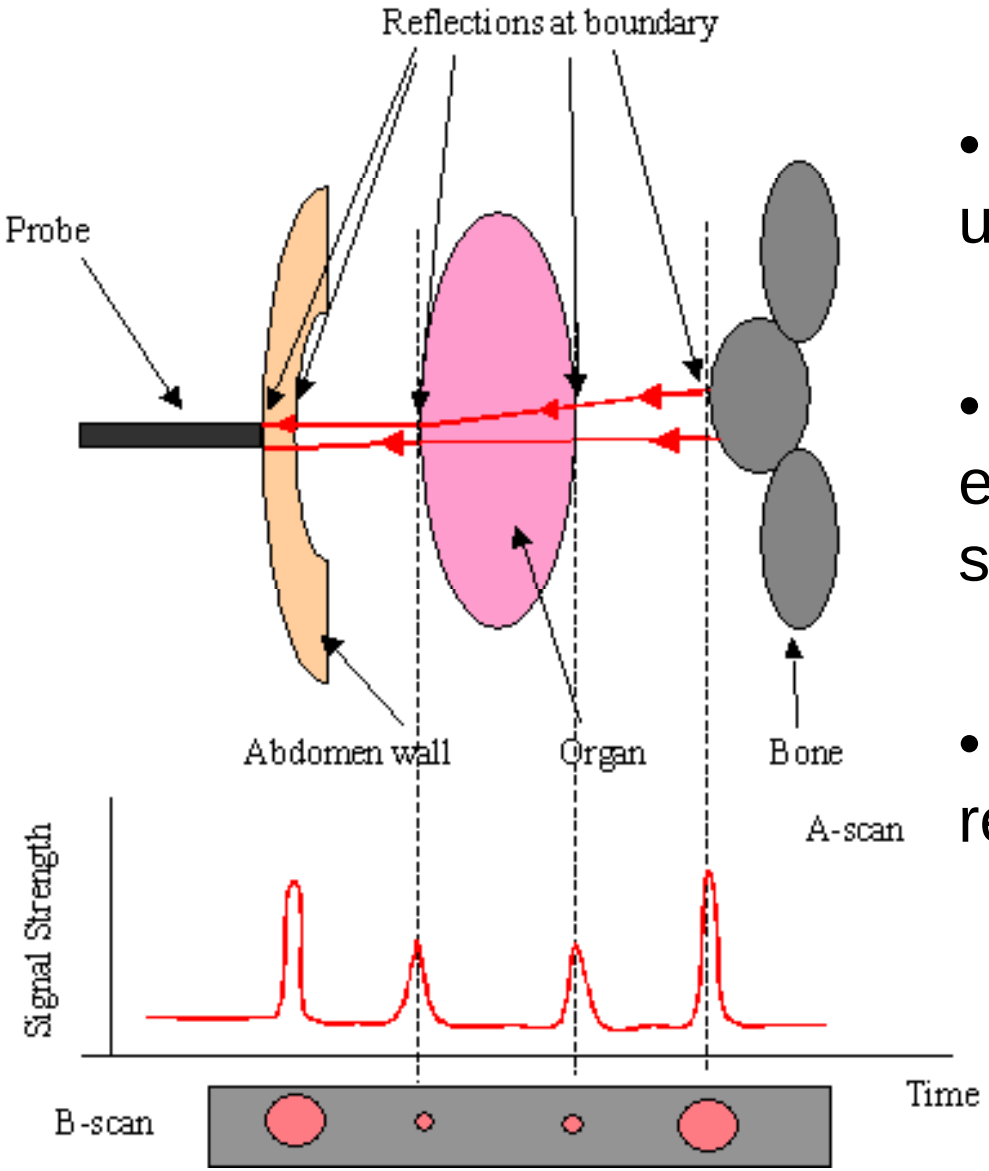
- Voltage source (0.025 Hz or DC) applied to the tissue.
- A 10 MHz focused transducer transmits and receives ultrasound pulses continuously to monitor the changes induced by the electric field.



Experimental setup

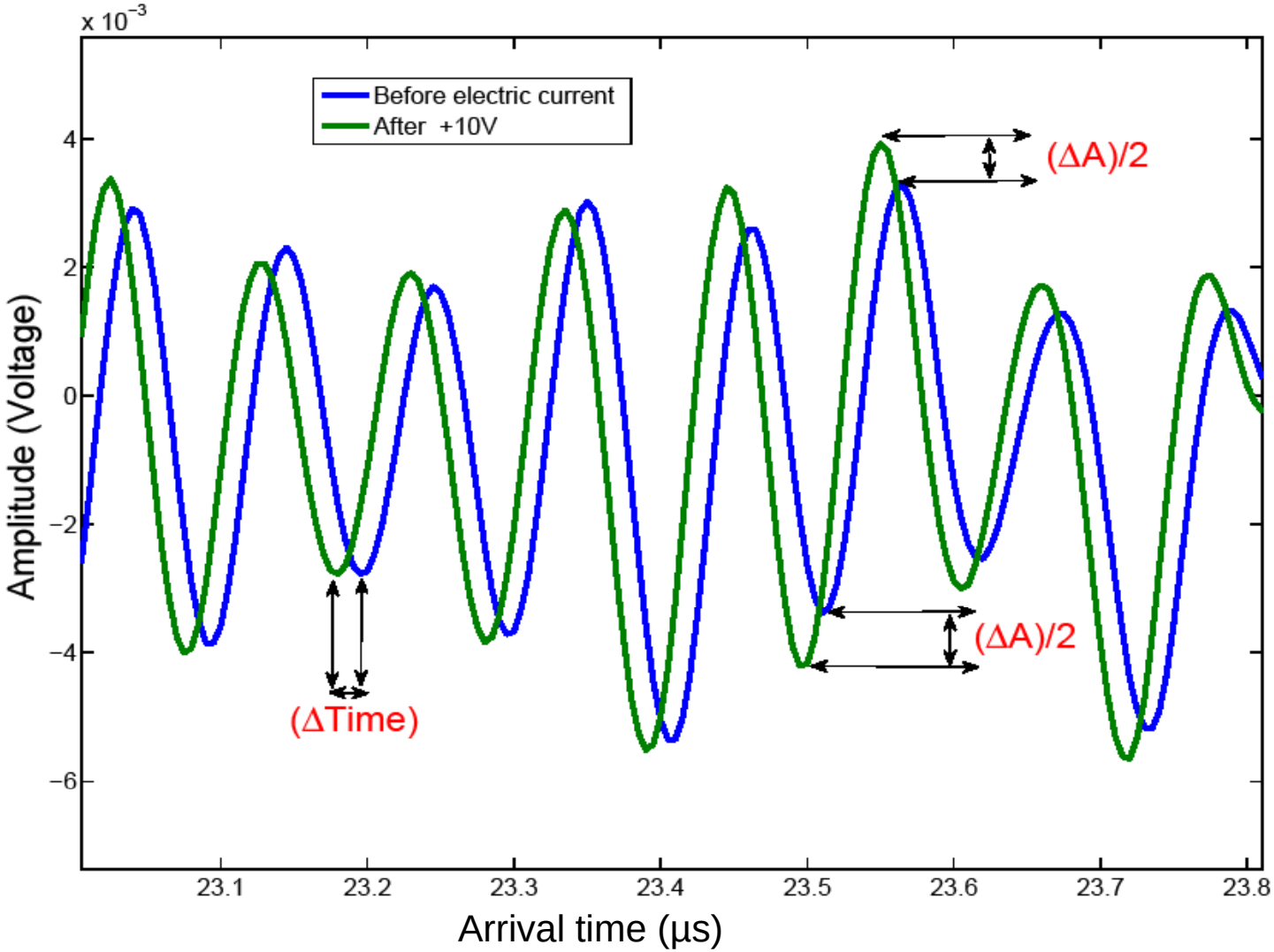
Electric field of 1 – 2 V/cm in the sample

Principles of Ultrasound Imaging: Echoes Scattered from Tissues



- Transducer generates ultrasound waves
- Reflection of sound energy by interfaces and scattering by cells
- Echo waves are received by transducer

Ultrasound Signals From a Piece of Porcine Heart Tissue Before and After Applying +10V

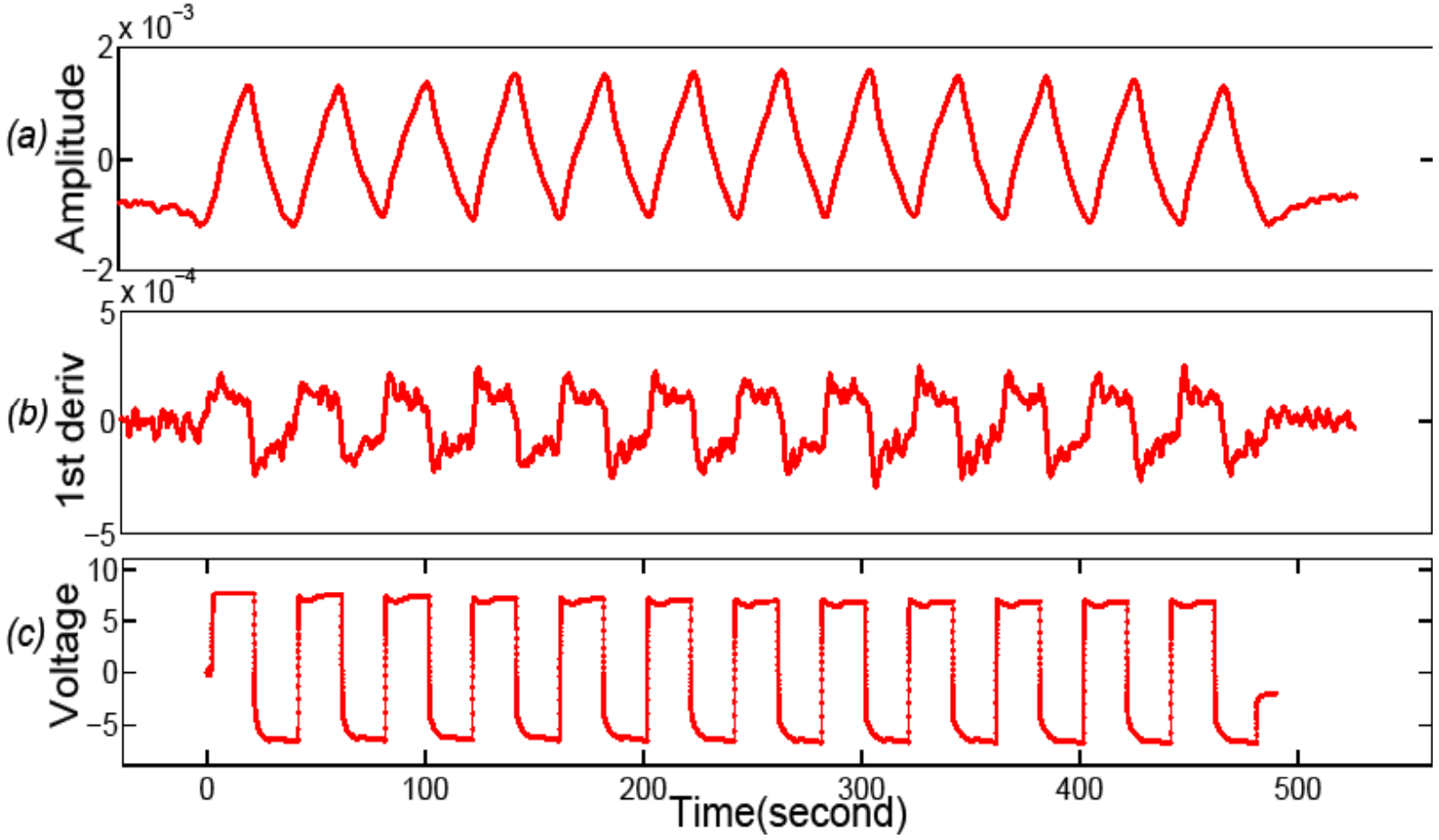


Correlation Between the Echo Amplitude and the Applied 0.025 Hz Voltage Source

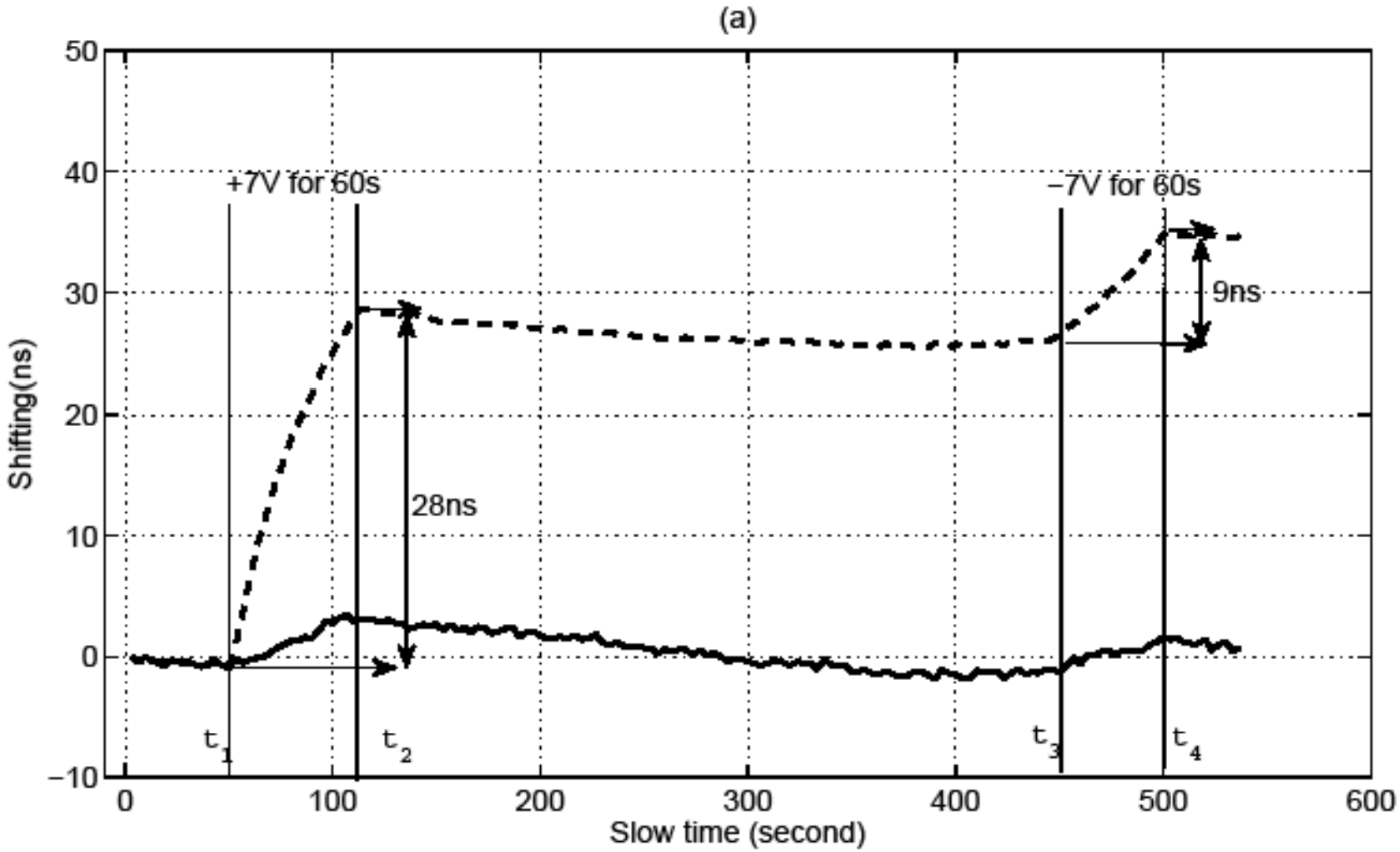
Amplitude of echo

Derivative of the amplitude

Applied voltage



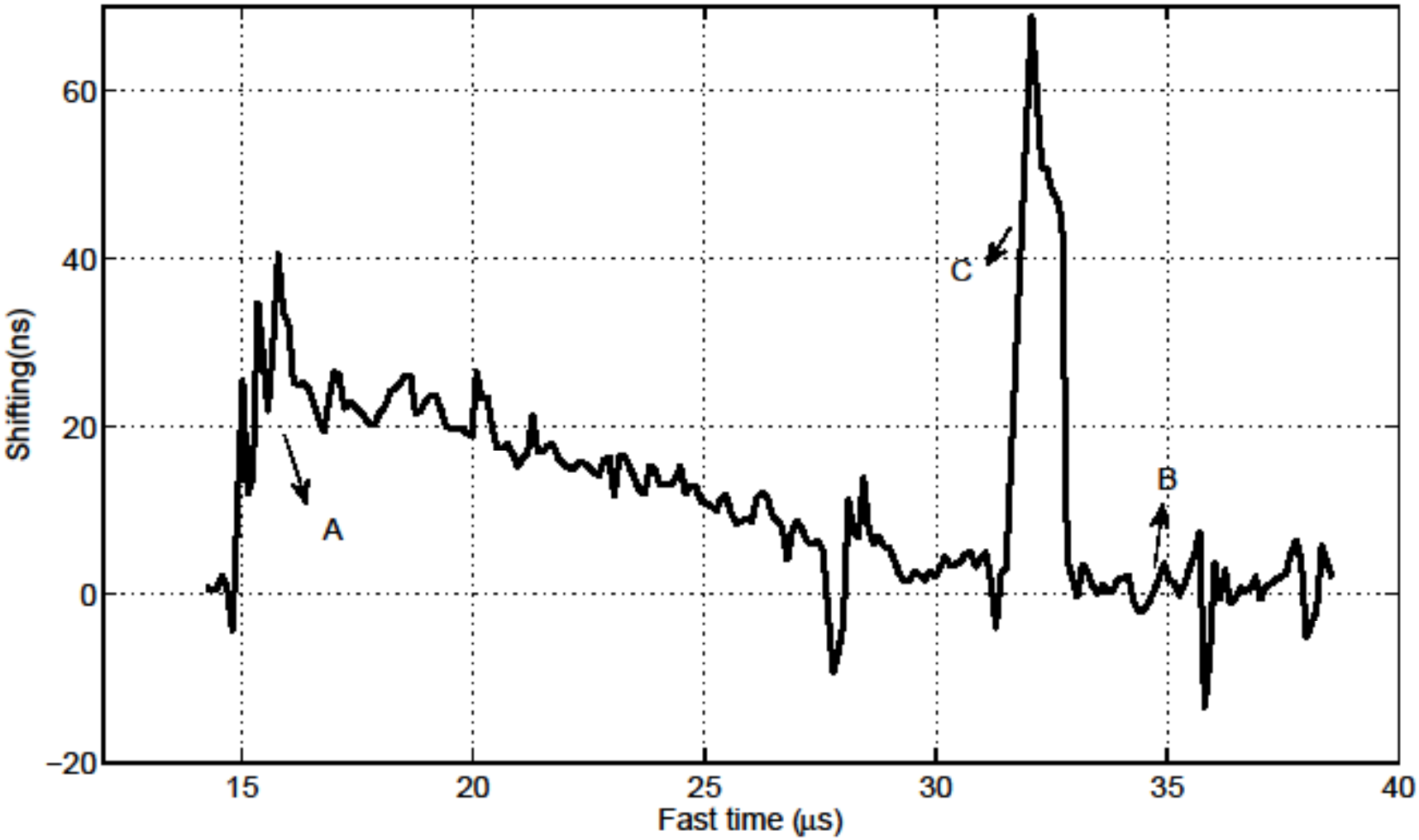
Shifting Of The Front and Rear Boundaries Of Sample



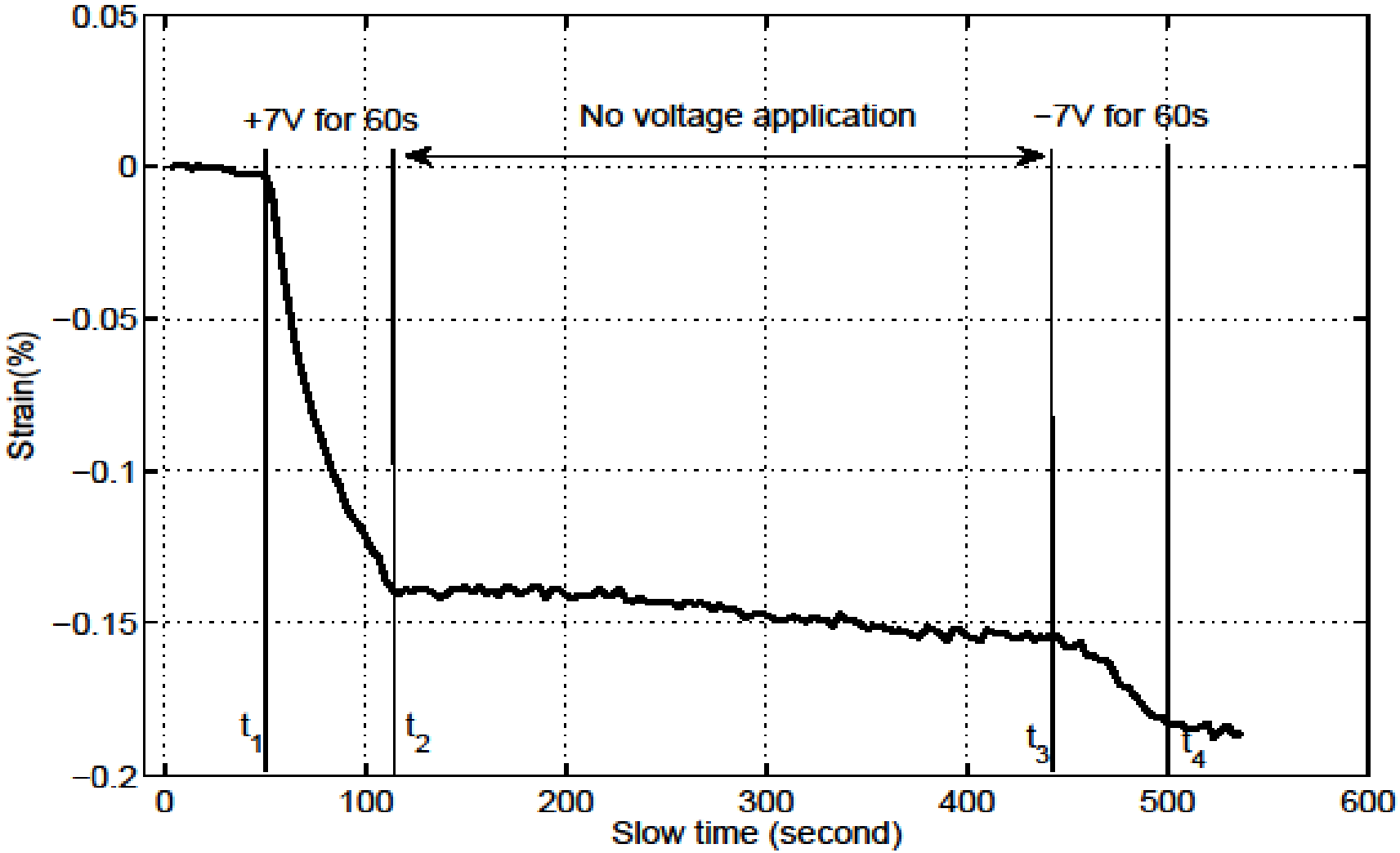
(1) 7 V applied, from $t_1 = 50s$ *to* $t_2 = 110s$.

(2)Negative 7 V applied, from $t_3 = 445s$ *to* $t_4 = 505s$.

Strain Induced by Applying 1 V/cm for 60 s

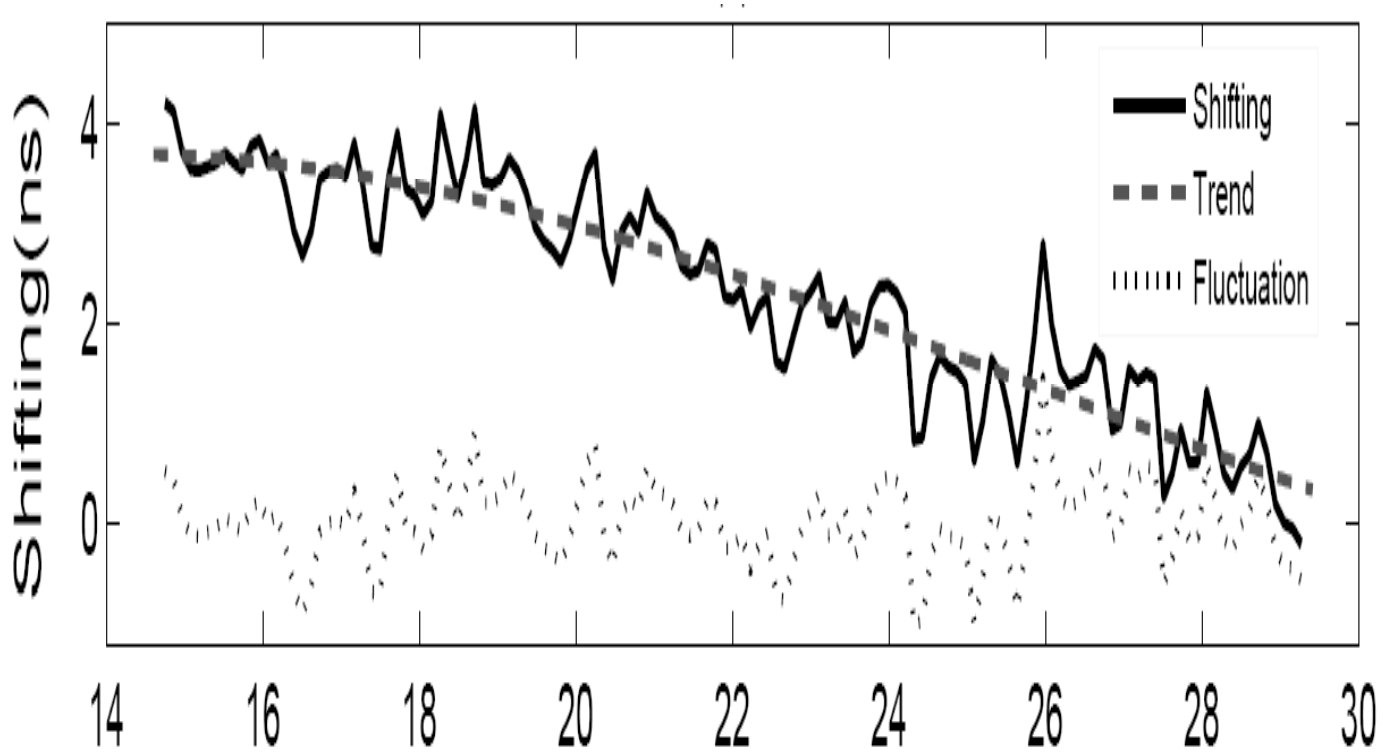


Strain Is Not Reversible By Applying Opposite Field



Similar changes were observed in heart tissue, muscle, liver, fat, and gelatin phantoms.

Decomposition of the Shifting into Trend and Fluctuation Components

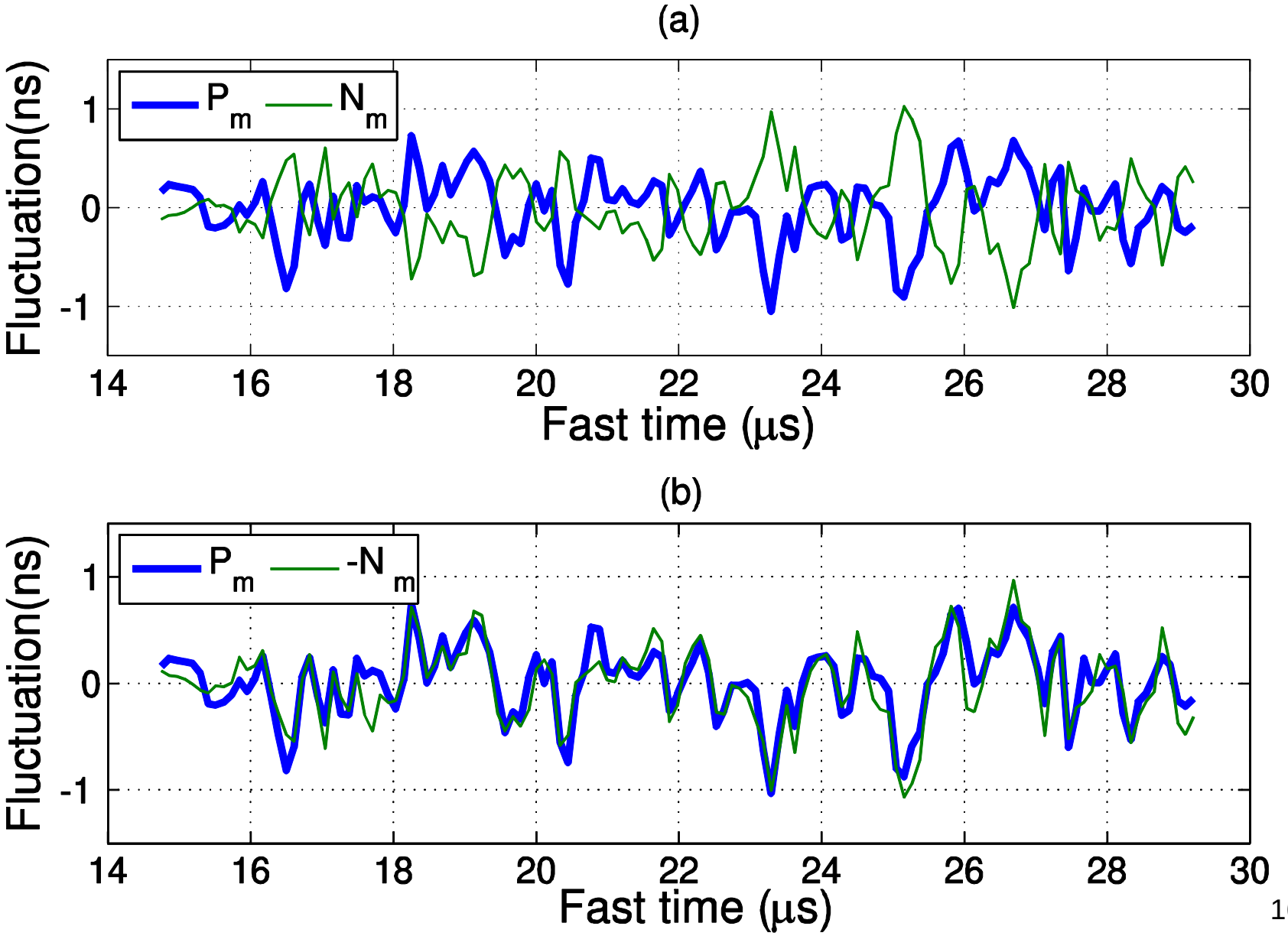


Fast time

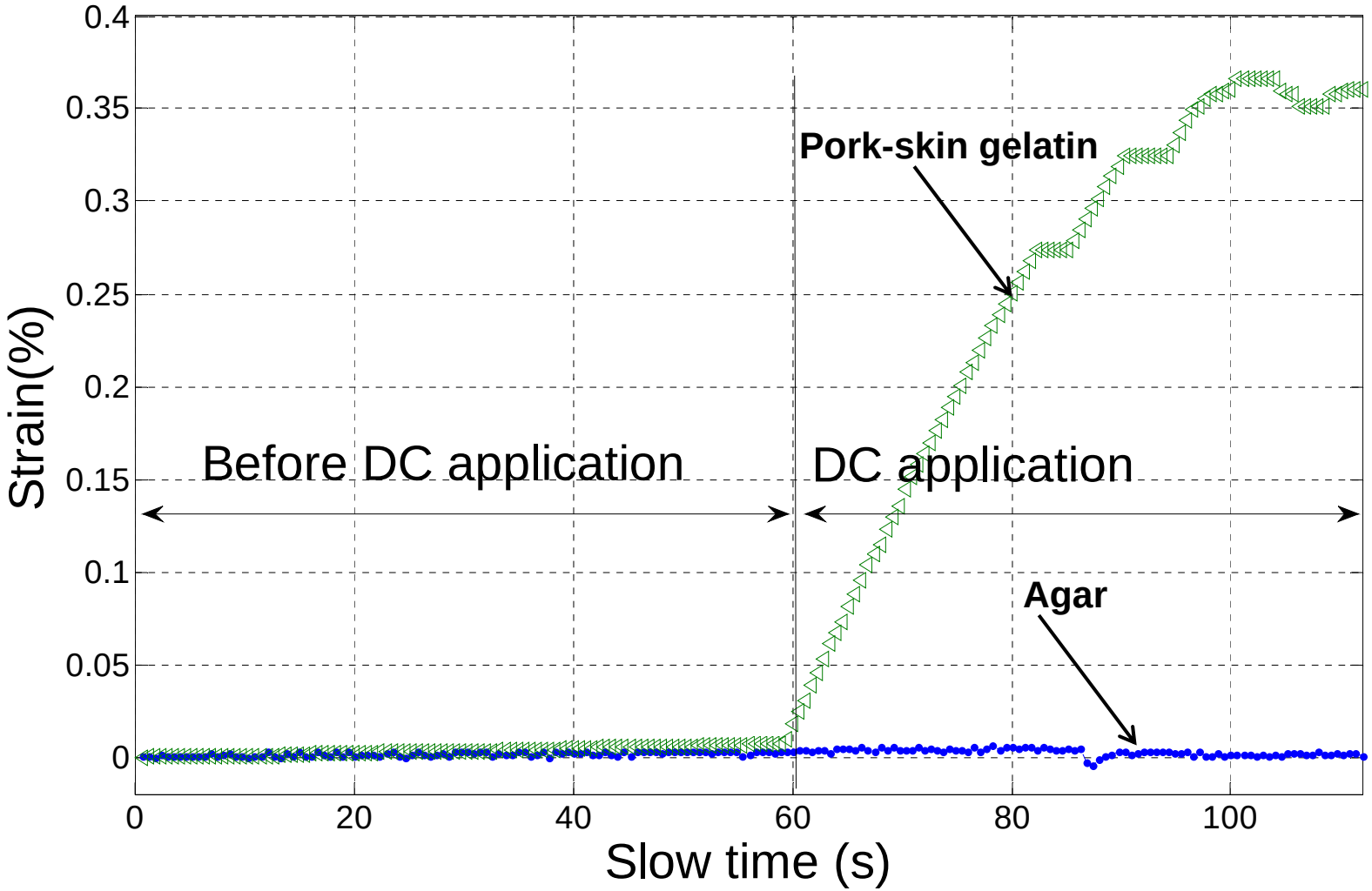
Trend is related with the strain in the sample.

Fluctuation is related with the decorrelation of RF signals

Decorrelation is Reversible By Applying Opposite Field

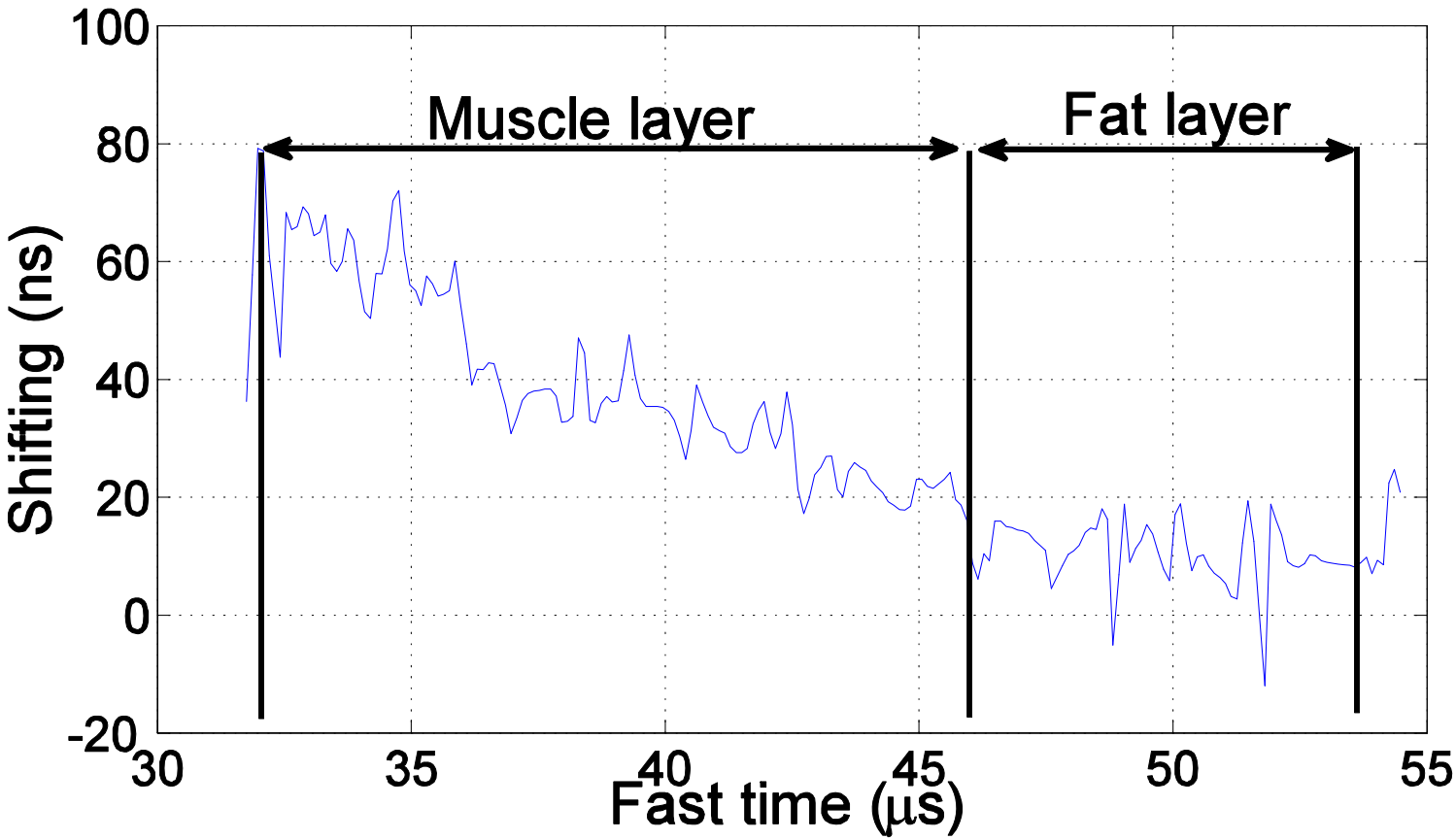


Agar and Pork-Skin Gelatin Phantom



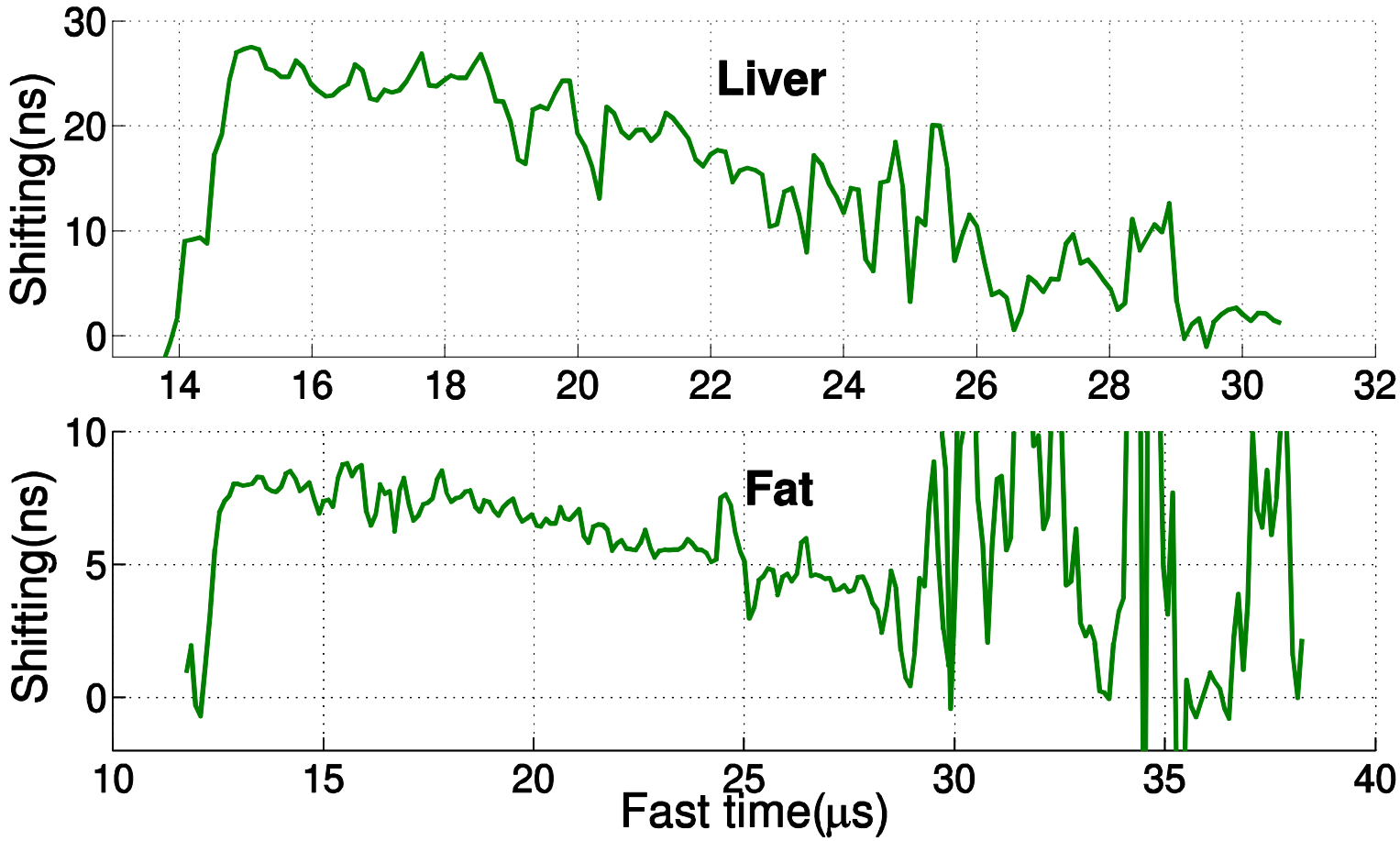
Agar has much smaller fixed charge density than pork-skin gelatin.

Shifting of a Two-layered Fat-muscle Sample



The strain in the muscle layer is much larger than the fat layer.

Shifting in Liver and Fat Tissues



Summary

- Strain and local changes in the amplitude are observed in the echo signal upon the electric current application.
- Amplitude change and decorrelation (fluctuation component of the shifting) can be nullified by applying opposite field.
- Strain is NOT reversible by applying opposite field.
- For muscle, liver, heart, and fat tissue changes at different magnitudes are observed.