High-Frequency Pulsed-Electro-Acoustic (PEA) Measurements for Mapping Charge Distribution

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Objective

- Use high-frequency pulsed-electro-acoustic (PEA) measurements as a non-destructive method to investigate internal charge distribution in dielectric materials

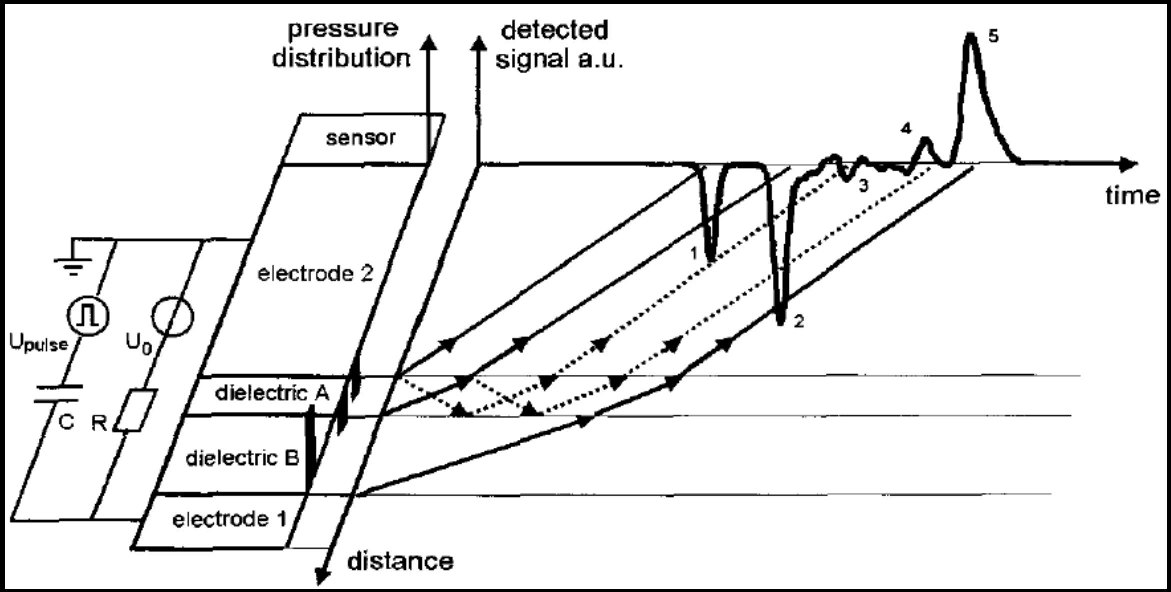
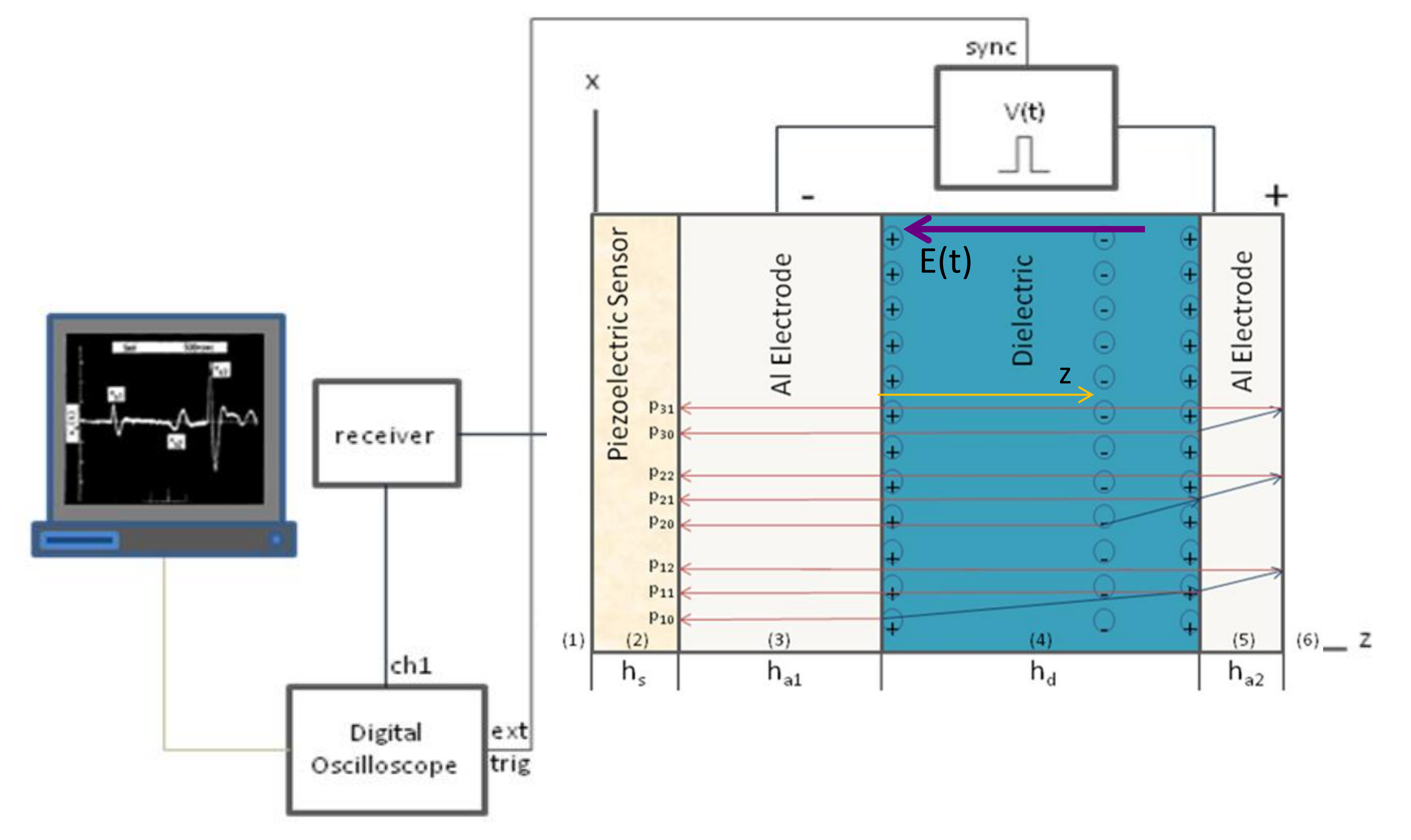


Figure 1. *Detected acoustic signal when a DC voltage is applied to a charged dielectric sample*

Approach

- Thin dielectric positioned between two conducting electrodes
- Voltage signal on the two electrodes to generate an electric field across the dielectric
- Force on embedded charge creates a pressure wave that propagates within the capacitor
- Coupled acoustic sensor measures the ensuing pressure pulse response
- Spatial distributions of the charge profile are obtained from the resultant pressure waveform

Model



sync
V(t)
x
-
+
E(t)
Piezoelectric Sensor
Al Electrode
Dielectric
Al Electrode
z
p31
p30
p22
p21
p20
p12
p11
p10
(1)
(2)
(3)
(4)
(5)
(6)
z
hs
ha1
hd
ha2
receiver
ch1
Digital Oscilloscope
ext trig

Theory

$$\Delta f(z,t) = \rho(z)\cdot\Delta z\cdot E(t)$$

$$\Delta f(\omega,z) = \rho(z)\cdot\Delta z\cdot E(\omega)$$

$$\Delta p(\omega,z) = p_0(\omega)\cdot\rho(z)\cdot\Delta z\cdot E(\omega)\cdot e^{ik_d z}\cdot e^{ik_a h_{a1}}\cdot t_{43}\cdot t_{32}$$

$$z = t\cdot c_d\ ;\ \Delta z = c_d\Delta t\ ;\ k_d = \frac{\omega}{c_d}$$

$$\Delta p(\omega,t) = p_0(\omega)\cdot E(\omega)\cdot c_d\cdot e^{ik_a h_{a1}}\cdot t_{43}\cdot t_{32}\cdot\rho(c_d t)\cdot e^{i\omega t}\Delta t$$

$$p(\omega) = p_0(\omega)\cdot E(\omega)\cdot c_d\cdot e^{ik_a h_{a1}}\cdot t_{43}\cdot t_{32}\cdot\int_0^t\rho(c_d t)\cdot e^{i\omega t}\cdot dt$$

$$p(\omega) = p_0(\omega)\cdot E(\omega)\cdot c_d\cdot e^{ik_a h_{a1}}\cdot t_{43}\cdot t_{32}\cdot\rho(c_d\omega)$$

$$p(t) = \mathrm{Re}\left[icfft\left[p(\omega)\right]\right]$$

$$\rho(c_d\omega) = \frac{p(\omega)\cdot e^{-ik_a h_{a1}}}{p_0(\omega)\cdot E(\omega)\cdot c_d\cdot t_{43}\cdot t_{32}}$$

$$p_{10}(\omega) = p_0(\omega)\cdot E(\omega)\cdot e^{ik_a h_{a1}}\cdot t_{32}$$

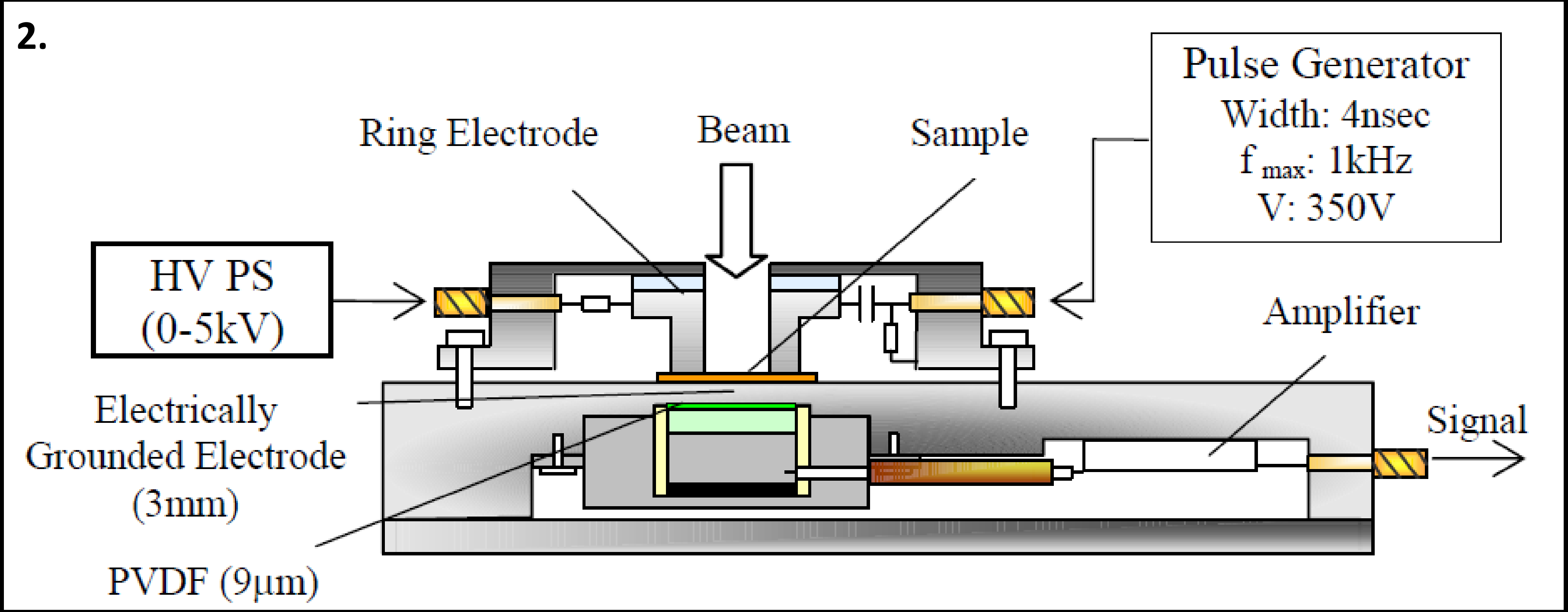
$$p_{20}(\omega) = p_0(\omega)\cdot E(\omega)\cdot c_d\cdot\rho(c_d\omega)\cdot e^{ik_a h_{a1}}\cdot t_{43}\cdot t_{32}$$

- Calculate Force on Electron Distribution Due to Applied Electric Field
- Change to Frequency Domain
- Account for Reflection and Transmission Coefficients
- Compute Inverse Fourier Transform
- Extract Waveform

Measurement System

- Purpose: study of charge migration under external fields

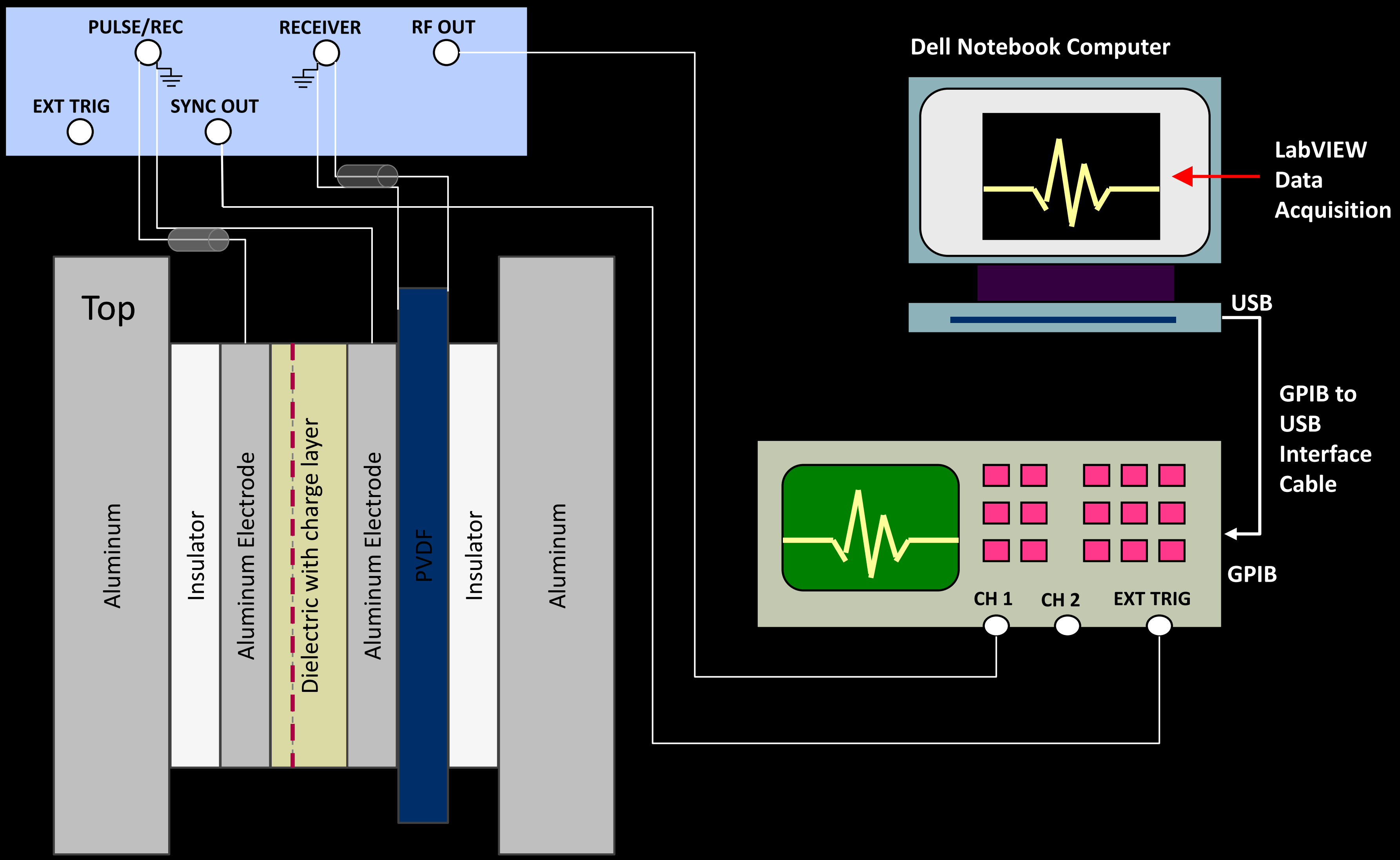
2.



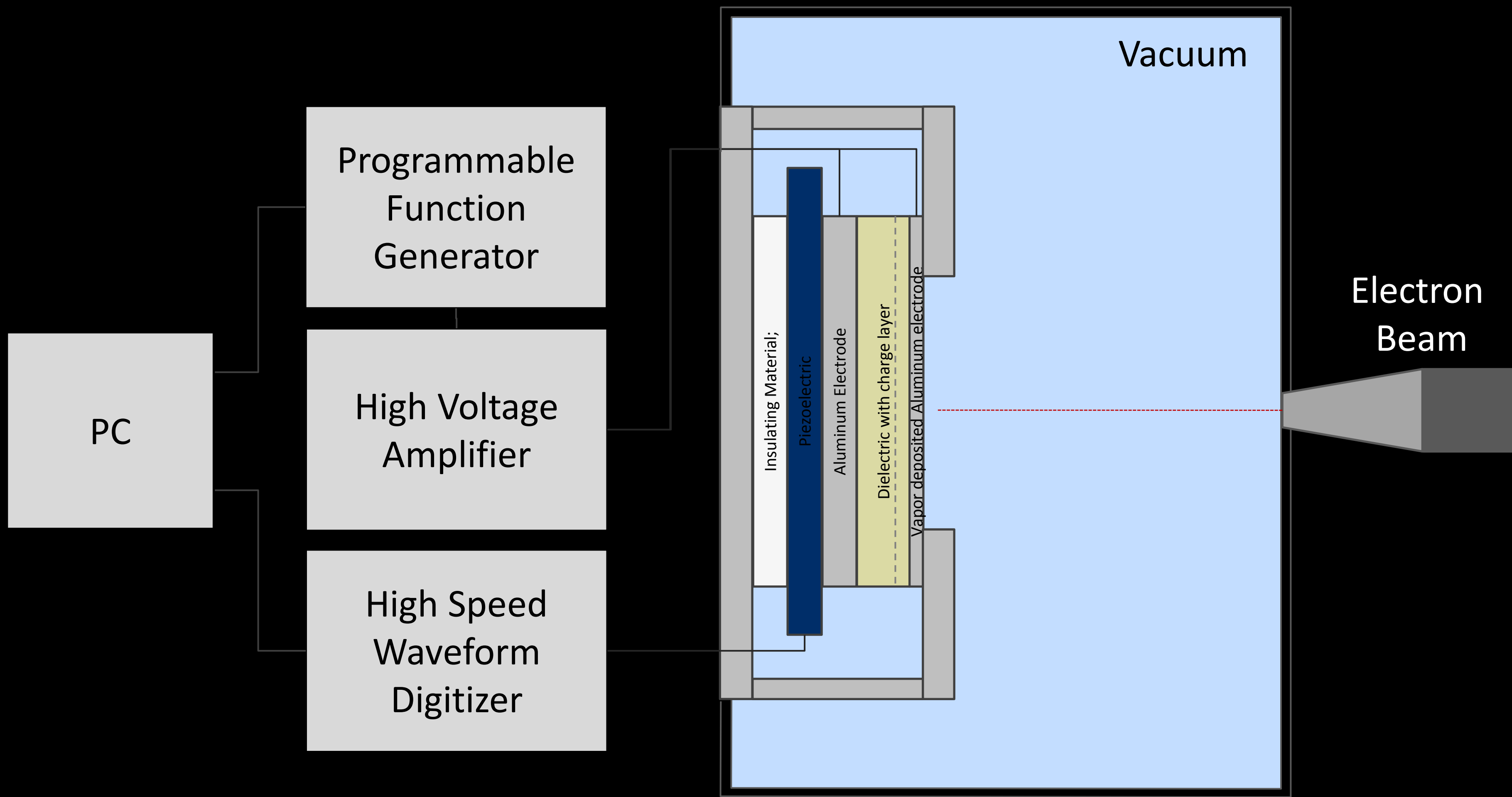
- Generation of a 0-5kV input from a DC field
- Electric field impulse created from 350V pulse generator
- Superimposition of impulse on 5kVDC input produces pressure wave

***Figure 2**. Schematic diagram and of the measurement apparatus. (Miyake 2010)*

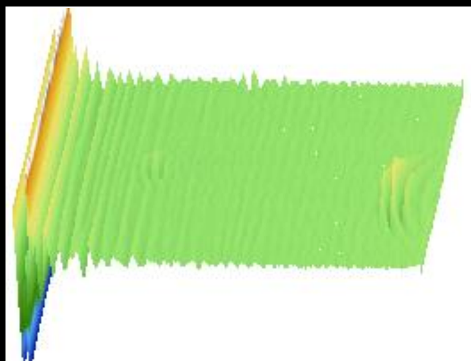
Experimental Procedure



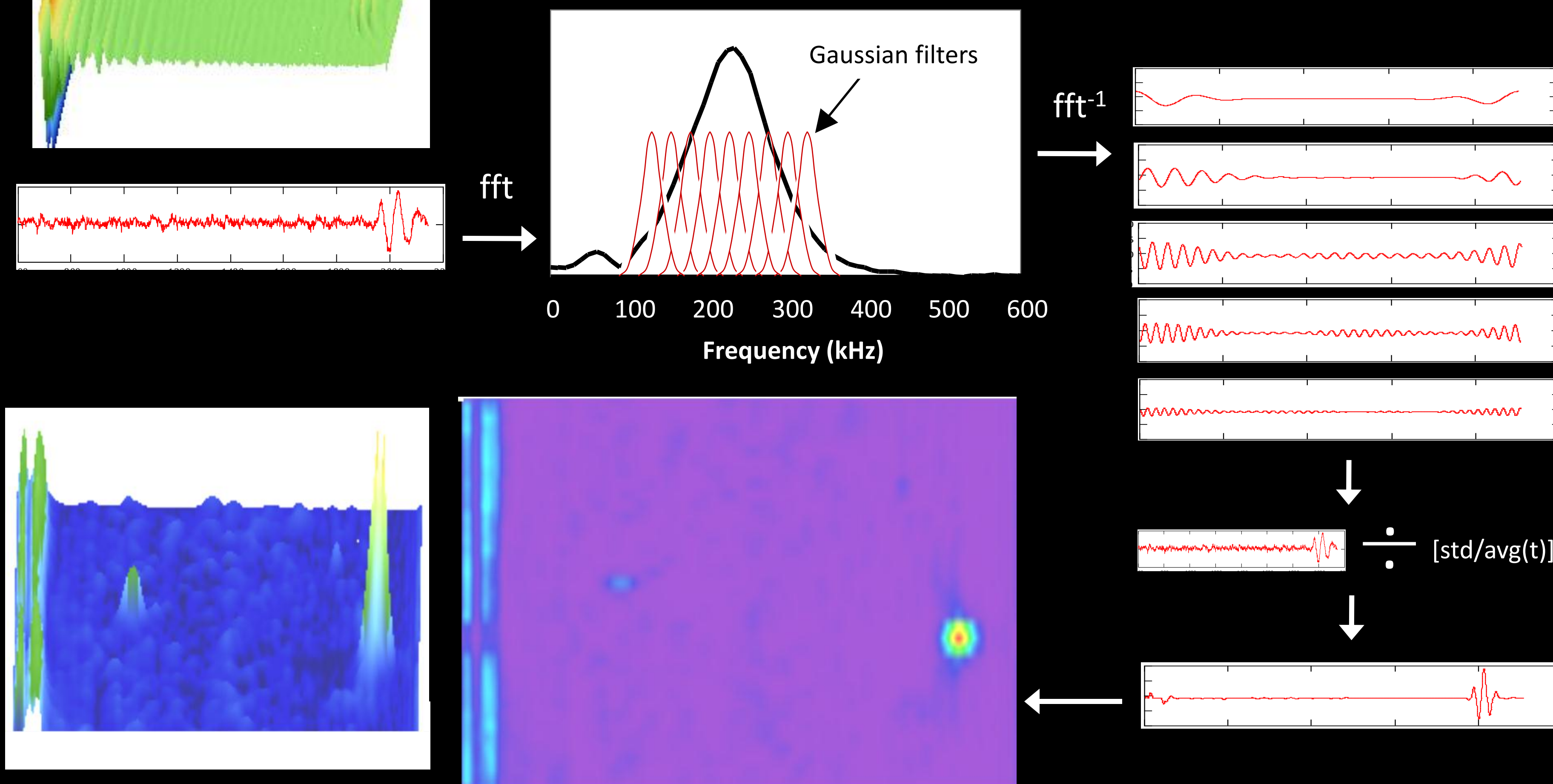
In Vacuo Experimental Set-up



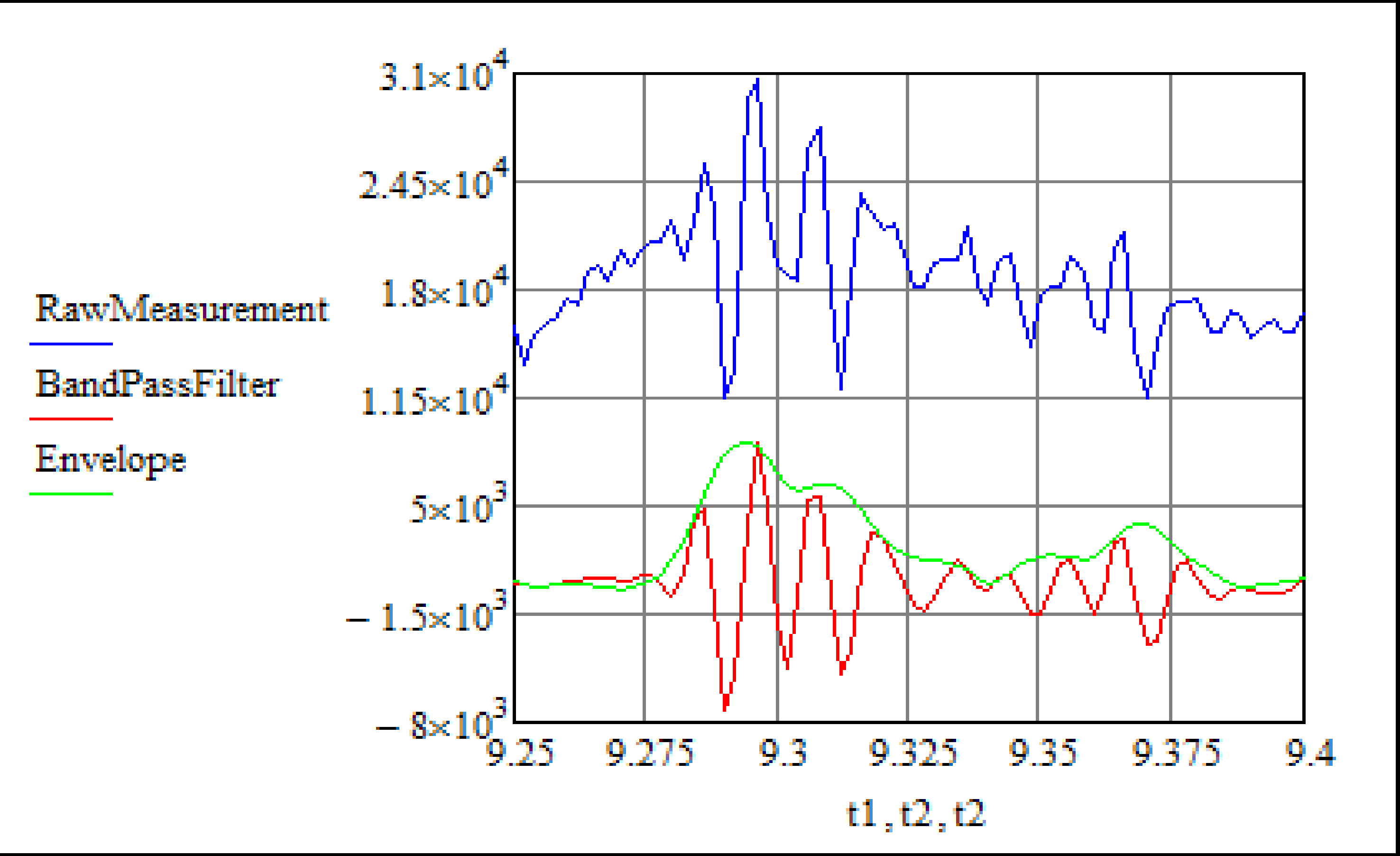
Signal Processing



Split-Spectrum Processing + Gaussian Filter + Synthetic Aperture + Envelop



Band Pass Filter and Envelope

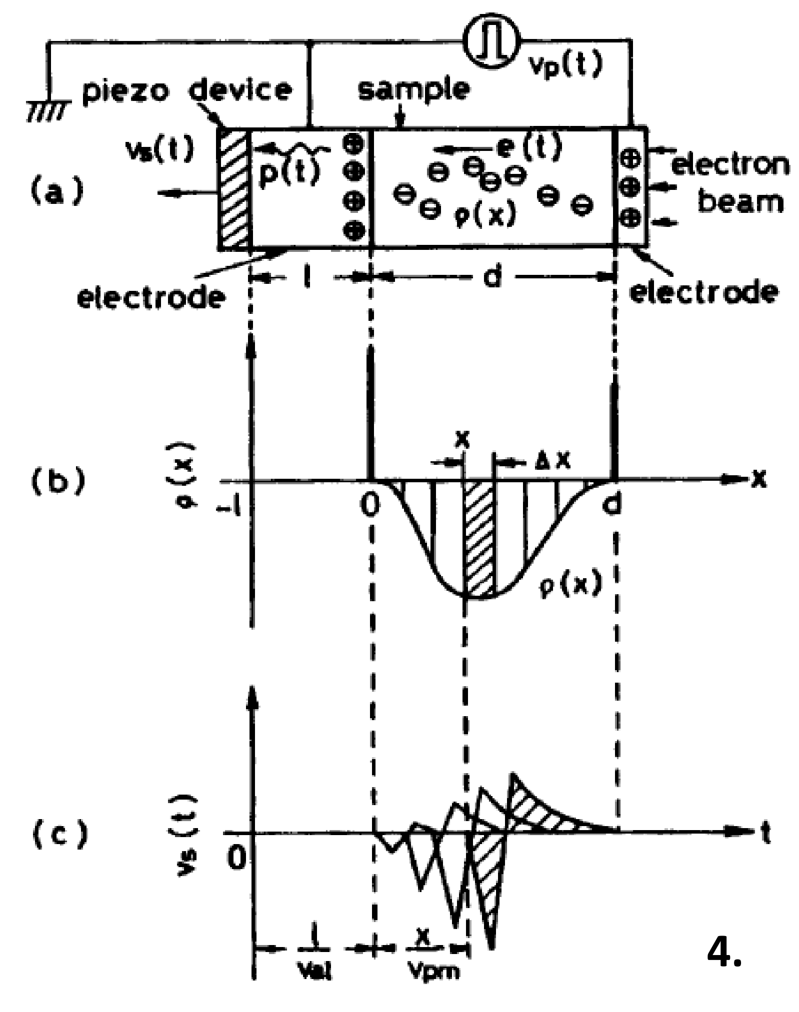


- Purpose: increase the signal-to-noise ratio

Discussion

- Validating existing PEA models requires
  - Understanding of wave propagation inside the PEA cell
  - Analysis of transducer geometry on the quality of output voltage signal
- Very thin (1-10μm) PVDF piezoelectric transducers necessary to improve spatial resolution
- Signal-processing may improve the signal-to-noise
- High vacuum and low energy conditions are allow direct electron beam irradiation

Conclusion



- Measurement and analysis of volume charge distribution in thin dielectrics using high-frequency (ultrasonic) waveforms will improve the prediction of charge distribution while seeking to validate and improve existing PEA models and theories

- ***Figure 3**: Relationship between distributed charge density ρ(x) in the sample and the output signal voltage $v_s(t)$ from the transducer of the piezoelectric device*

Citations, Acknowledgements

Citations

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Questions?

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