Ultrasonic imaging parameters ~Attenuation coefficient

Advisor: Pai-Chi Li

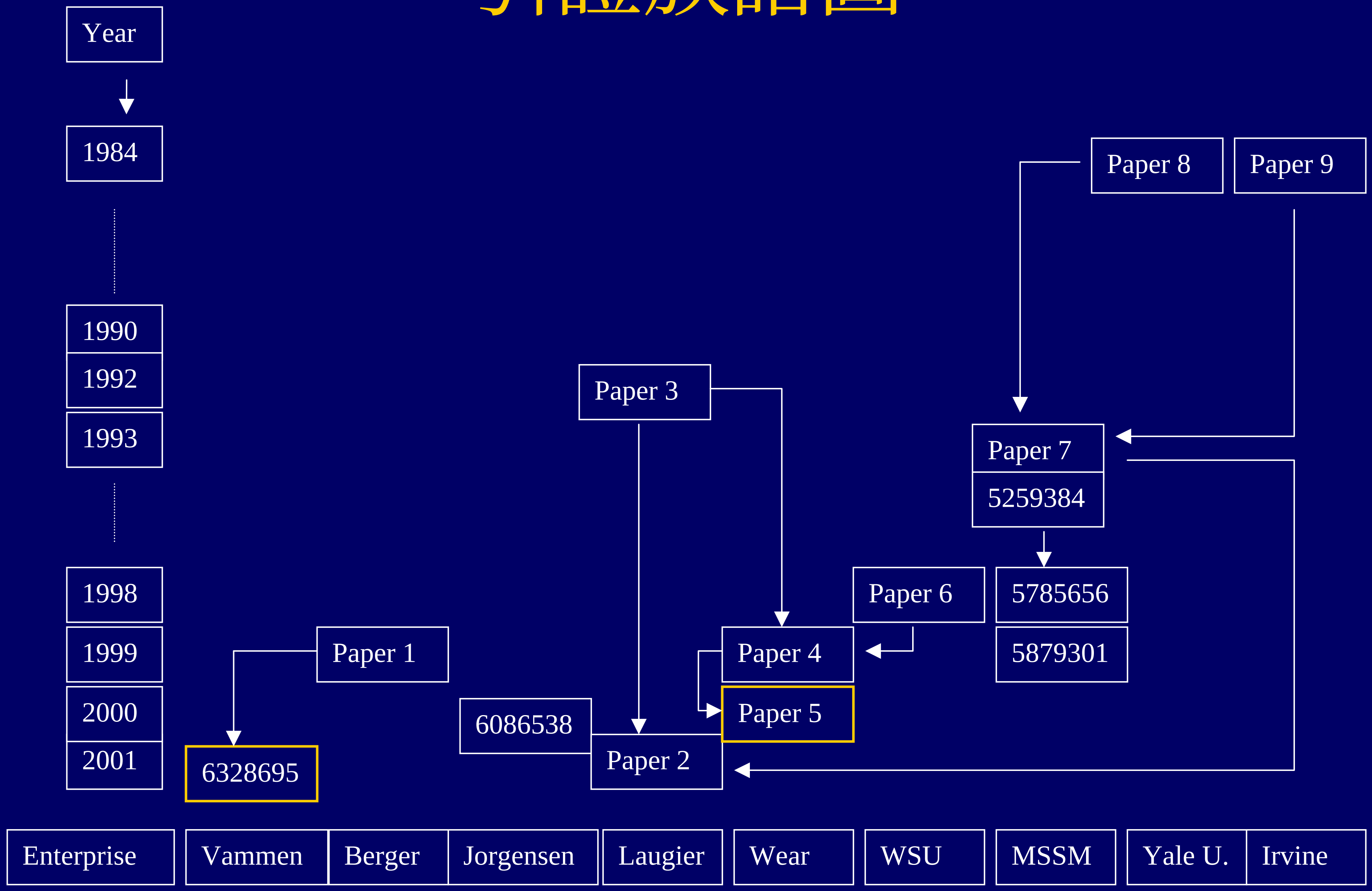
Student: Mei-Ru Yang

Wei-Ning Lee

	Device	Circuit	Method	Apparatus	System	Process	Total
Attenuation coefficient	1	0	31	17	0	1	50

Ultrasound attenuation in bones (two transducers)		********** ****
Ultrasound attenuation in bones (one transducers)		***
Ultrasound attenuation in other tissues(breast dermis…)		****
Attenuation predicted by Biot’s theory (bone)		****
Ultrasound attenuation in signal processing		*********

引證族譜圖


Year
1984
1990
1992
1993
1998
1999
2000
2001
Paper 1
Paper 2
Paper 3
Paper 4
Paper 5
Paper 6
Paper 7
Paper 8
Paper 9
5259384
5785656
5879301
6086538
6328695
Enterprise
Vammen
Berger
Jorgensen
Laugier
Wear
WSU
MSSM
Yale U.
Irvine

Methods and Apparatus

- One transducer (pulse-echo mode)
  - Spectral - Shift
  - Log Spectral – Difference
  - Backscattering
- Two transducers(one transmitter and one receiver)

One Transducer

- Simplify the handling and avoid potential errors to misalignment or mismatching
- Differentiate the attenuation coefficients of adjacent tissues
- Problem : renewed reflection
  - The delay should preferably by adapted to space any mirror images of pronounced spikes away from the region to be analysis

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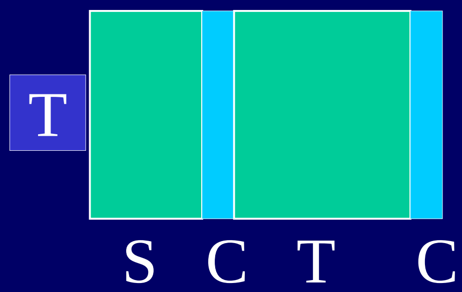
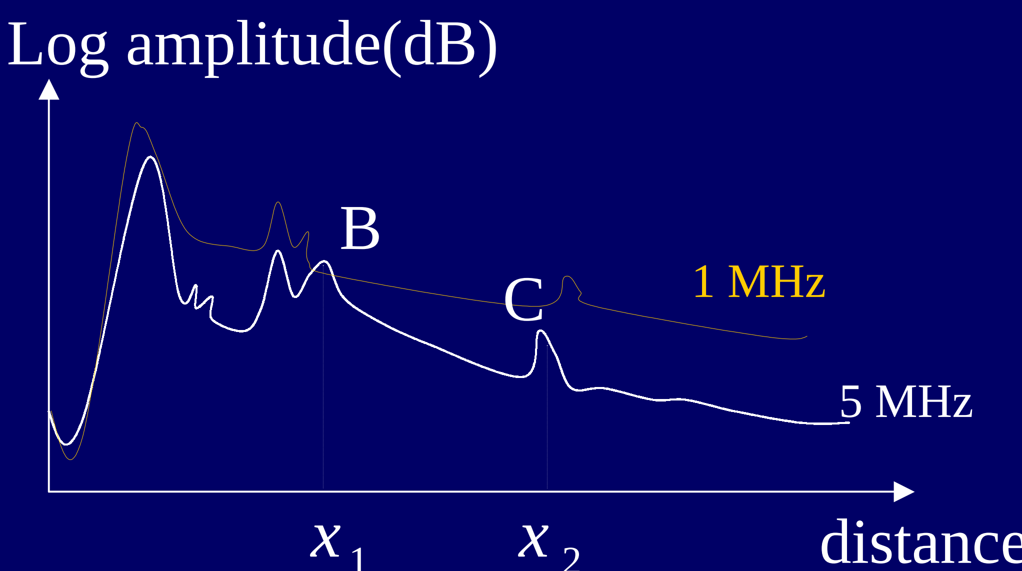




$$A(x) = A(x_o) \cdot e^{-\alpha x}$$

A: amplitude

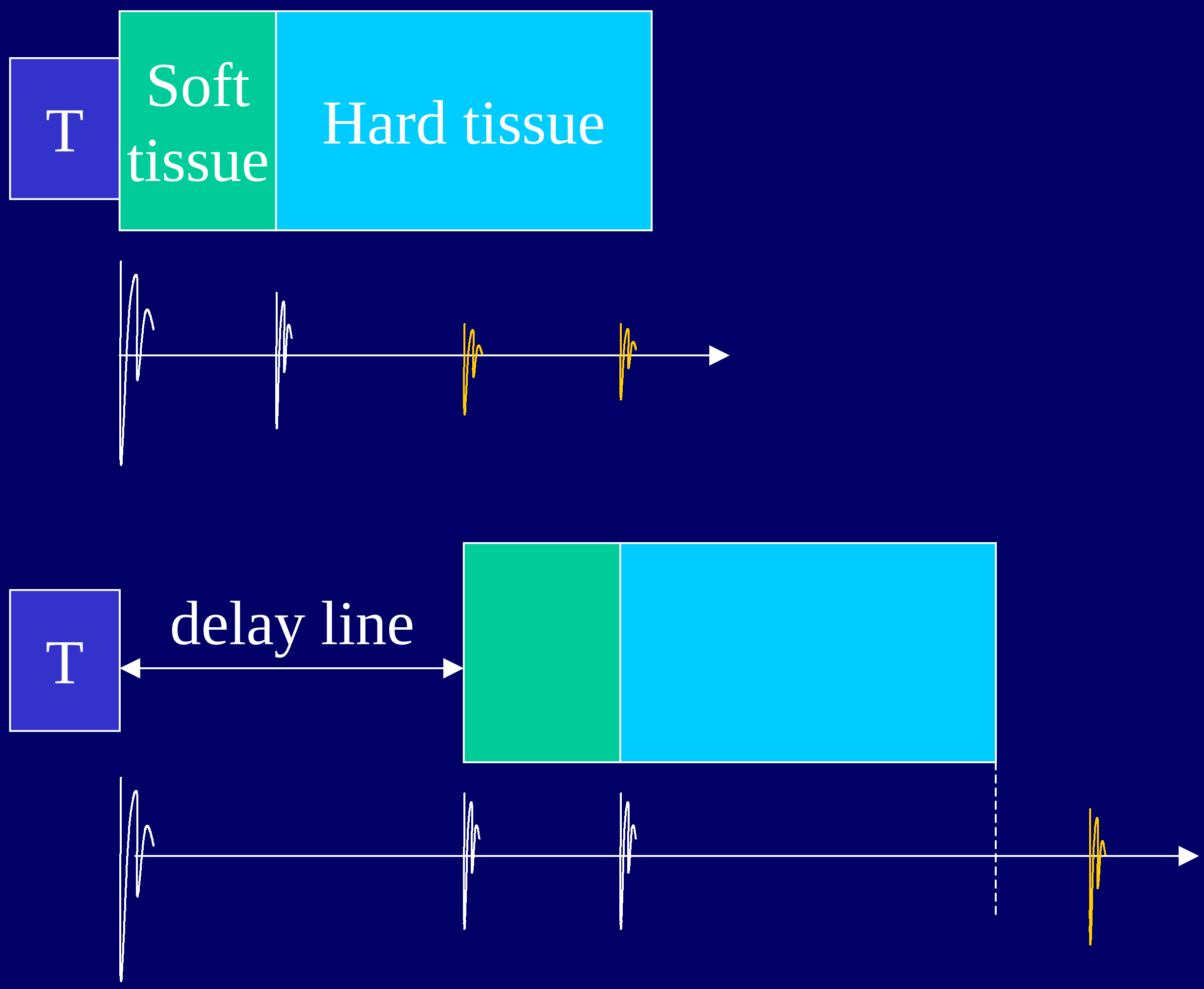
x: distance

α: attenuation

$$\alpha = \frac{\ln A(x_1) - \ln A(x_2)}{x_1 - x_2}$$

$$\alpha(f) = \beta \cdot f^{n}$$

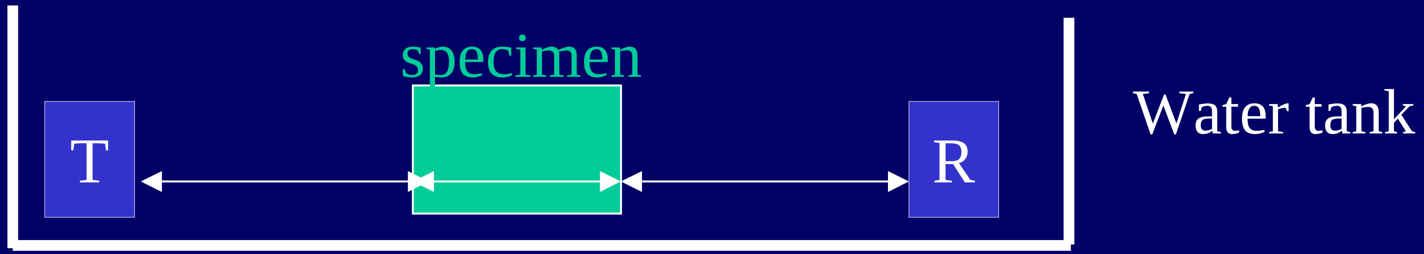
Interpose a delay line (50mm)



Two Transducers

- Through-transmission method
- A pair of transducers coaxially in a water tank
- Submerge a sample between the transducers
- Signals were recorded both with and without the specimen in the acoustic path
- Can’t separate the contribution caused by effects in the soft tissue from the contributions caused by effects in the bone tissue

Apparatus



$$T = t_1/2 \quad + \quad t_s \quad + \quad t_2/2$$

$$L = \frac{t_1 \cdot v_w}{2} + t_s \cdot v_s + \frac{t_2 \cdot v_w}{2}$$

$$v_s = ?$$

t_1, t_2: pulse-echo mode

Spectral Shift Technique

P_r : transmitting pulse power spectrum

P_t : receiving pulse power spectrum

T: time constant

$$P_t(f) = c_i e^{-[2\pi T(f - f_t)]^2}, \quad f > 0$$

$$|H(f)|^2 = e^{-4\pi\beta f d}, \quad f > 0$$

$$P_r(f) = |H(f)|^2 P_i(f) = c_0 e^{-[2\pi T(f - f_r)]^2}$$

$$f_r = f_t - \frac{\beta d}{2\pi T^2} \Rightarrow \beta = \frac{2\pi T^2 (f_t - f_r)}{d}$$

Log Spectral Difference Technique

$$P_s(f) = T^4 e^{-2L\alpha(f)} P_w(f)$$

$P_s(f)$: power spectra recorded with the specimen sample

$P_w(f)$: power spectra recorded without the specimen sample

L: the specimen thickness

$\alpha(f)$: the frequency-dependent attenuation

T: the amplitude transmission coefficient at each specimen/water interface

if transmission losses are negligible

$$\Rightarrow \alpha(f) = \frac{1}{2L}[\ln P_w(f) - \ln P_s(f)]$$

Cont'd

- Attenuation obeys $\alpha = \beta \quad f^{n}$
- Use amplitude and phase information of the pulse
- Ultrasound reflection at the water-specimen interface →produce error

$$\alpha(f) = \frac{1}{L}\ln(1 - R^2) + \frac{1}{L}\ln\left[\frac{A_w(f)}{A_s(f)}\right]$$

$A_w(f)$: amplitude spectrum with water path only

$A_s(f)$: amplitude spectrum with the specimen inserted

L : specimen thickness

Cont'd

$$P(f) = \alpha(f) - \alpha(f_0) = \frac{1}{L}\ln\left[\frac{A_w(f)A_s(f_0)}{A_s(f)A_w(f_0)}\right]$$

$$Q(f) = \frac{1}{V_p(f_0)} - \frac{1}{V_p(f)} = \frac{\phi_w(f_0) - \phi_s(f_0)}{2\pi f_0 L} - \frac{\phi_w(f) - \phi_s(f)}{2\pi f L}$$

$$P^*(f) = \beta(f^n - f_0^n)$$

$$Q^*(f) = -\frac{\beta}{2\pi}\tan\left(\frac{n\pi}{2}\right)(f^{n-1} - f_0^{n-1})$$

Minimize

$$TSE = k\frac{\sum_{i=1}^{m}\left[p(f_i) - p^*(f_i)\right]^2}{\sum_{i=1}^{m}\left[p(f_i)\right]^2} + (1-k)\frac{\sum_{i=1}^{m}\left[Q(f_i) - Q^*(f_i)\right]^2}{\sum_{i=1}^{m}\left[Q(f_i)\right]^2}$$

Given "n", calculate attenuation coefficient β

Diffraction Correction

- Diffraction effect on attenuation estimate due to the two media with different ultrasound velocities
- Experimental Diffraction Correction technique
  - Using the spectrum of the reference media, i.e. water

$$\hat{\beta} = \frac{-20\left[\log_{10} A_e(f,z) - \log A_r(f,z)\right]}{|f|d}$$

$$\beta = \frac{-20\left[\log_{10} A_e(f,z) - \log_{10} A_r(f,z) - \log_{10} A_d(f,z)\right]}{|f|d}$$

Ad(f, z)：diffraction magnitude transfer function

Cont'd

- Fresnel parameter : S=Sa=z λ $_a$/a^2

$$S_w^* = z_w^* \lambda_w / a^2 = S_a \longrightarrow z_w^* = \frac{\lambda_w (z_a - d) + \lambda_s d}{\lambda_w}$$

z_w^* ensures that the water-specimen-water and water- only paths undergo equivalent diffraction effects

Then, $\beta_{EDC} = \frac{-20\left[\log_{10} A_e(f,z) - \log_{10} A_r(f,z_w^*)\right]}{|f|d}$

λ_s : wavelength in water

λ_w : wavelength in specimen

Difficulties

- Theoretical value
  - Biot's theory (for bone)
  - Ultrasound properties of mammalian tissues
  - Numerous parameters are required for the computation (bulk modulus, shear modulus, transmission coefficient, etc.)
- Three phantoms
  - Actual attenuation coefficients are unknown

Strategies for Attenuation Estimate

- Qualitative analysis
  - Use various specimens with largely different hardness
  - Observe the attenuation trend
  - Relationship between attenuation and frequency
- Quantitative analysis
  - Dispersion & reflection
  - Diffraction correction

Experiment

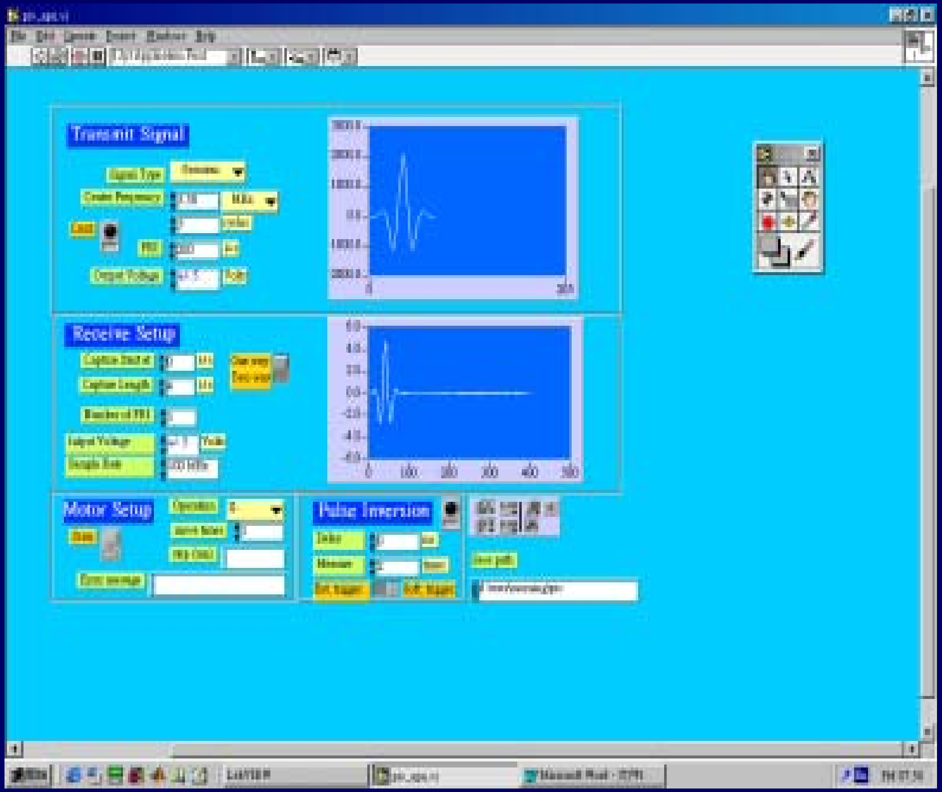
- Transducers: 3.5 MHz

  5 MHz

  7.5 MHz
- Pulse receiver
- Oscilloscope
- A/D: GaGe fs=100 MHz
- LabView
- Phantom

Preliminary Results

- Transmitting mode
  - Signal type: Gaussian
  - 4 cycles, continuous
  - PRI: 300 μ s
  - Output voltage: $\pm$ 5 V
- Receiving mode
  - Capture length: 5 μ s
  - No. of PRI: 1
  - Sampling rate: 50 MHz



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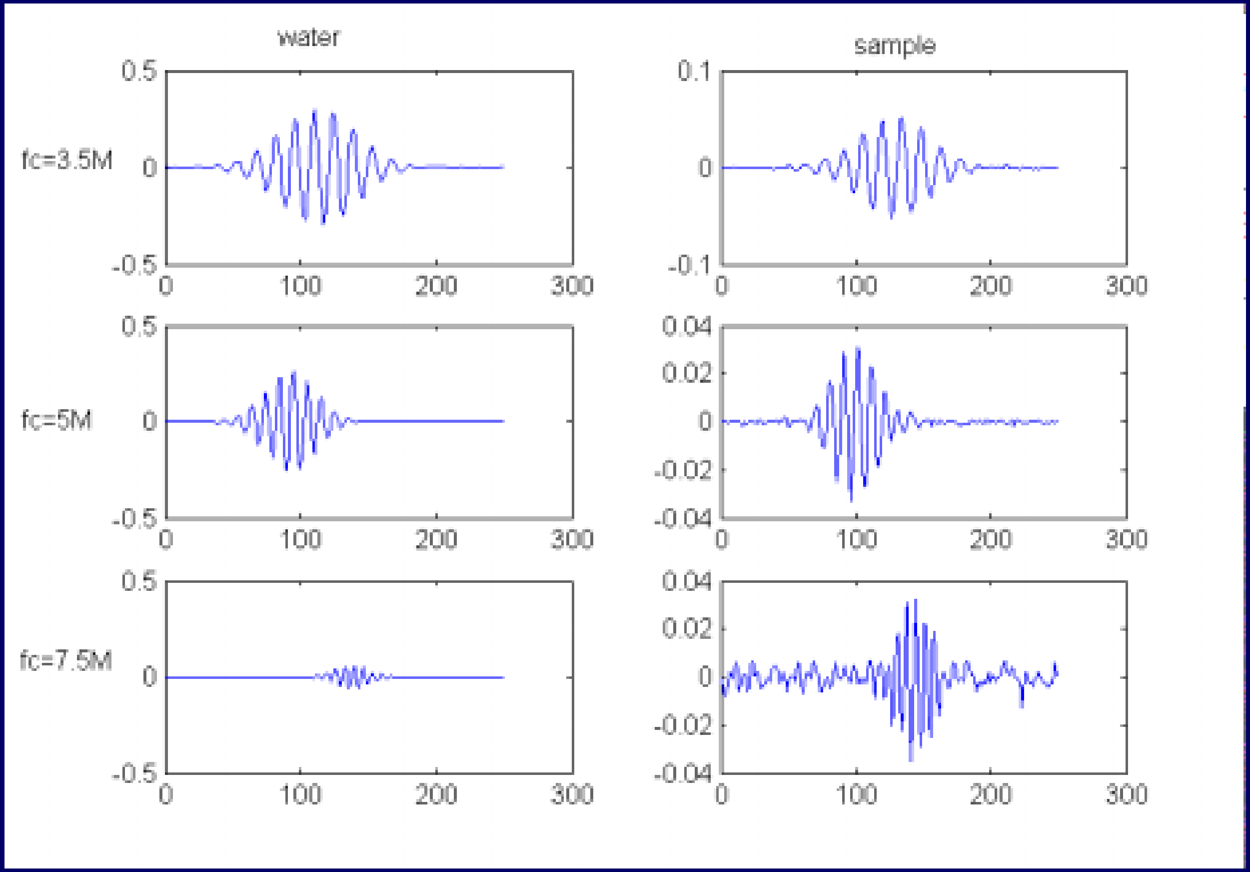
water
sample
fc=3.5M
fc=5M
fc=7.5M
0.5
0
-0.5
0.1
-0.1
0.04
0.02
-0.02
-0.04
0
100
200
300

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