The Theory and Analysis of Reflection Coefficient

Some applications of the chirp sonar

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Acoustic density measurements of consolidating cohesive sediment beds by means of a non-intrusive "Micro-Chirp" acoustic system

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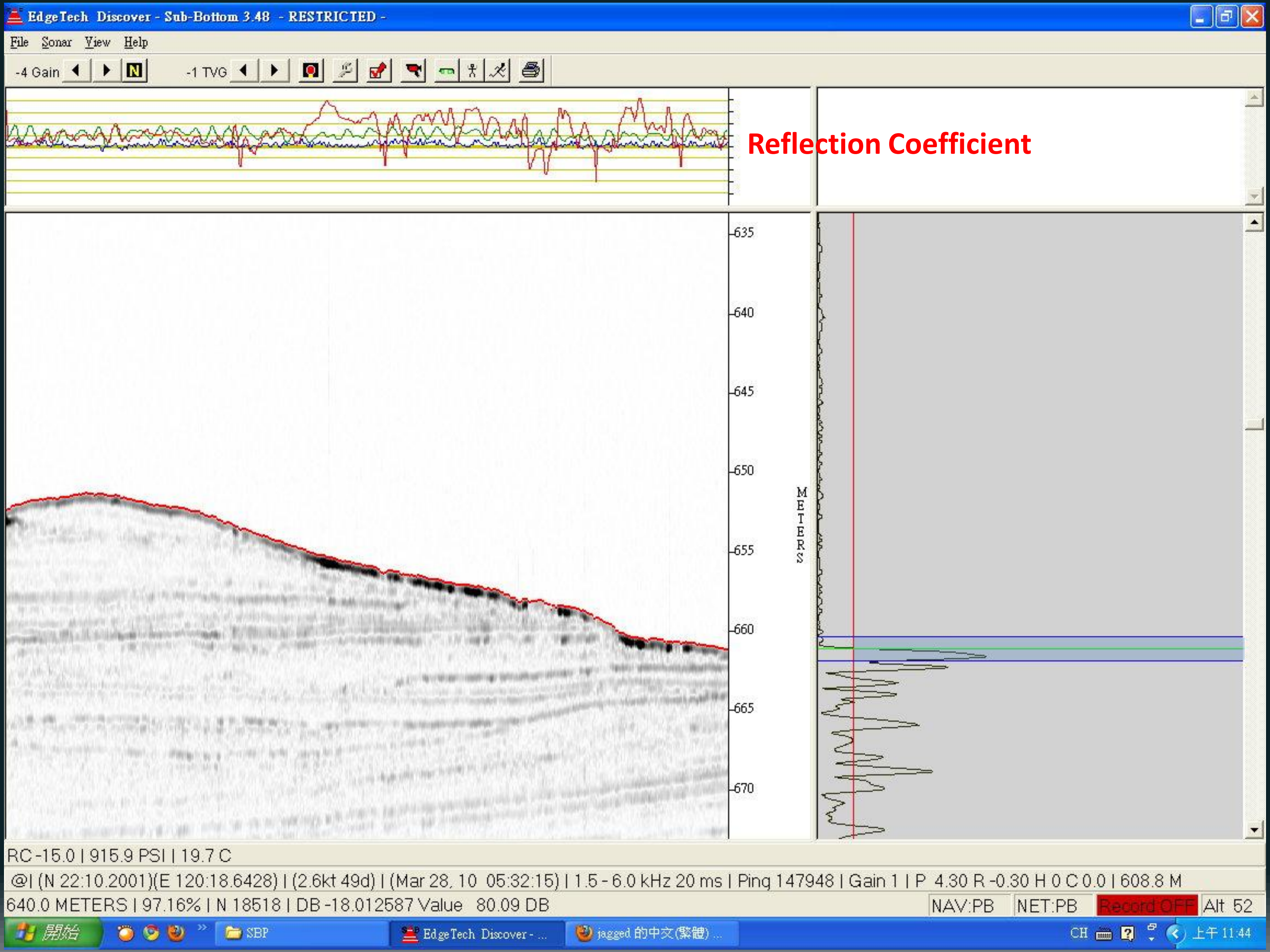
Reporter : Lin Chih-Wei



Reflection Coefficient

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RC -15.0 | 915.9 PSI | 19.7 C
@| (N 22:10.2001)(E 120:18.6428) | (2.6kt 49d) | (Mar 28, 10  05:32:15) | 1.5 - 6.0 kHz 20 ms | Ping 147948 | Gain 1 | P  4.30 R -0.30 H 0 C 0.0 | 608.8 M
640.0 METERS | 97.16% | N 18518 | DB -18.012587 Value   80.09 DB          NAV:PB   NET:PB   Record OFF   Alt  52
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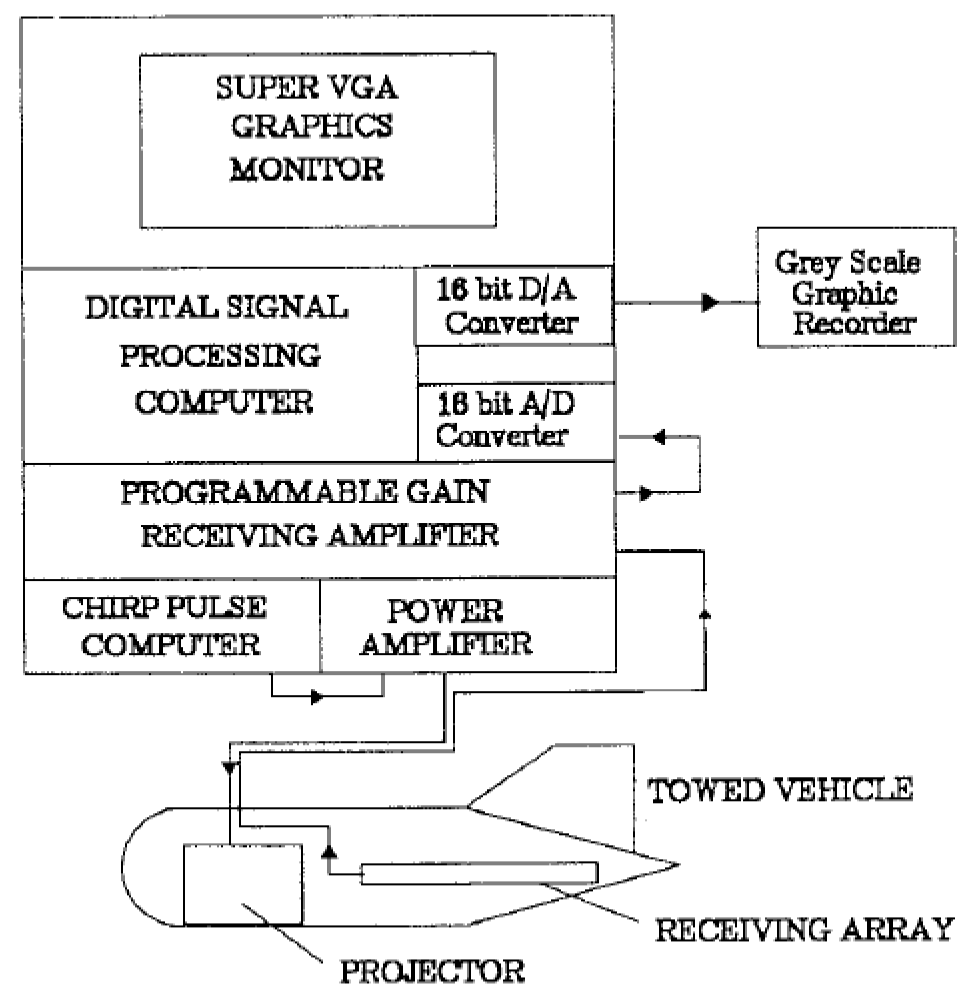
Outline

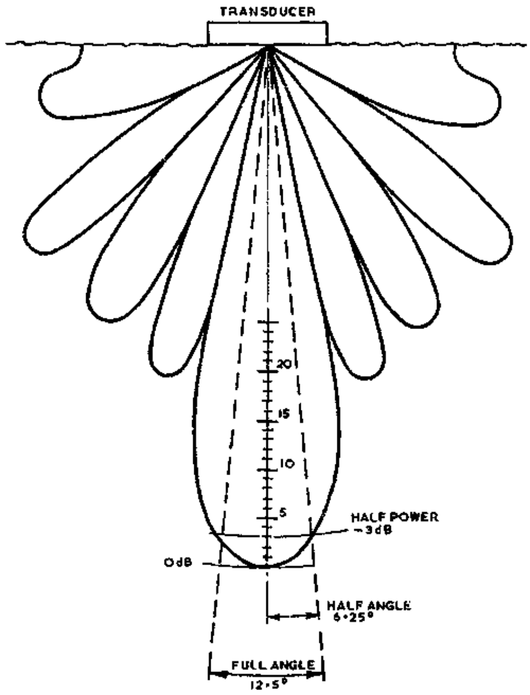
- ☐ Introduction
- ☐ Chirp sonar system description
- ☐ The digital signal processing
- ☐ Acoustic density measurements of consolidating cohesive sediment beds
- ☐ Conclusion

Introduction

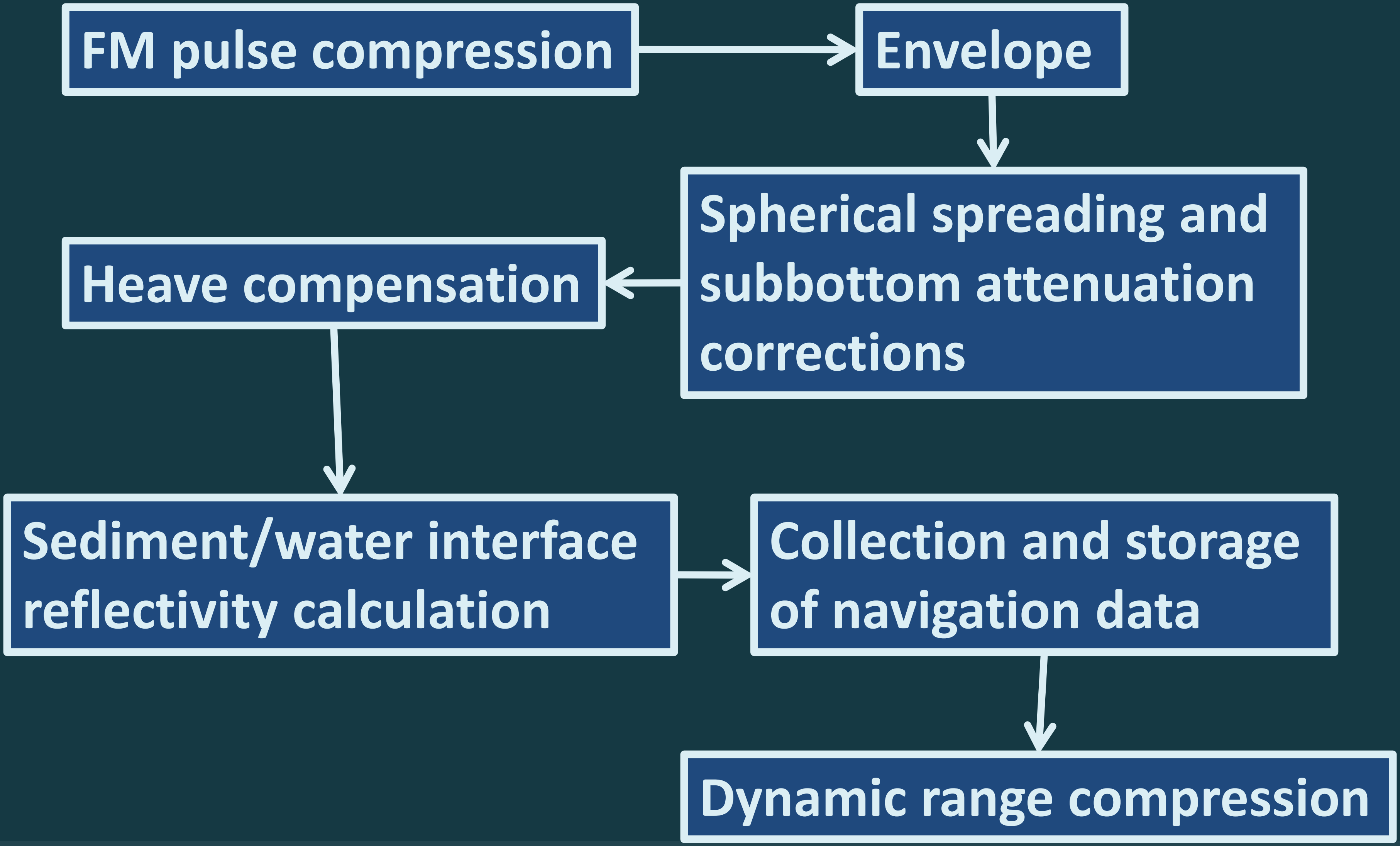
- The chirp sonar is a towed digital , swept FM subbottom profiler
- High resolution images of the underlying sediment structure and for estimating acoustic parameters such as reflectivity , effective attenuation and volume scattering strength of sediment layers
- Using a 20 msec 1.5-10 kHz FM sweep , generated images showing a vertical resolution of 15cm
- To classify sediments , coring is the direct way to estimate bulk density but a time- and labor-intensive procedure . The measured reflection coefficient can provide the high spatial and temporal resolutions
- Predicted sediment types by calculating the spectrum of the subbottom reflections

Chirp sonar system description





the digital signal processing



FM pulse compression

Envelope

Spherical spreading and subbottom attenuation corrections

Heave compensation

Sediment/water interface reflectivity calculation

Collection and storage of navigation data

Dynamic range compression

FM pulse compression using matched-filter processing

$$y(t) = h(t) * x(t)$$

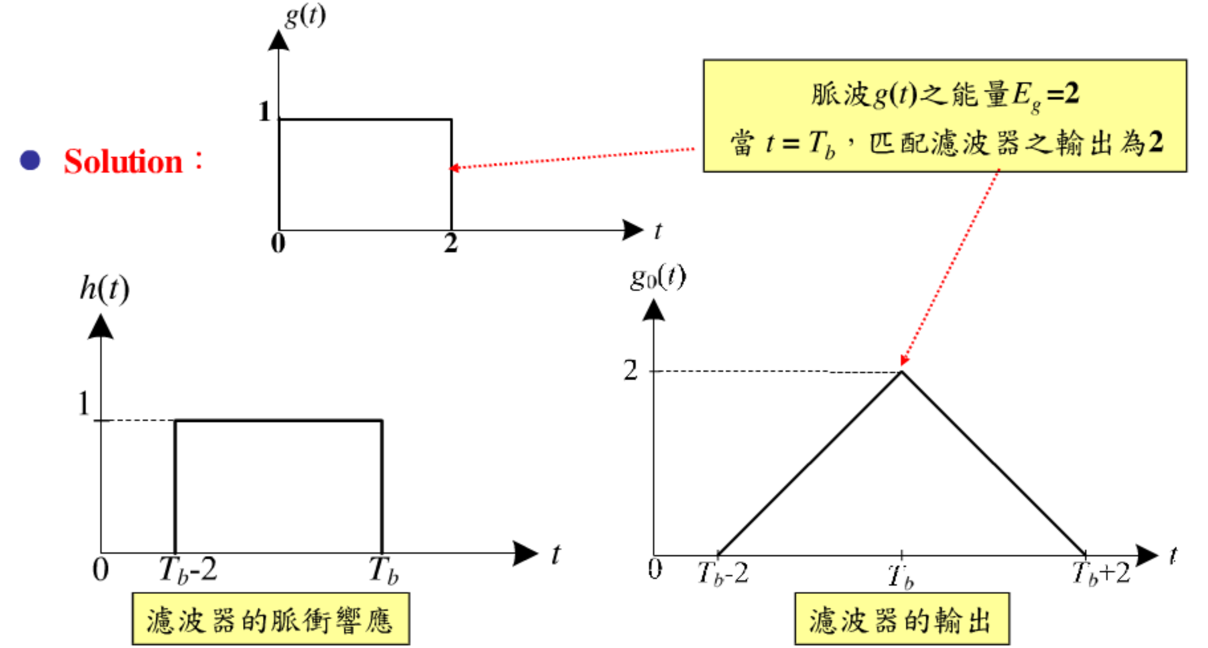
$$d(t) = h(t) * e(t)$$

$$\left(\frac{S}{N}\right)_{out} = \frac{y^2(t_b)}{E(d^2(n))} = \frac{\left|\frac{1}{2\pi}\int_{-\pi}^{\pi} H(e^{jw})X(e^{jw})e^{jwt_0}dw\right|^2}{\frac{1}{2\pi}\int_{-\pi}^{\pi}\left|H(e^{jw})\right|^2 P_{ee}(w)dw}$$

Using Schwarz's inequality

$$h(t) = C \cdot x(t_b - t)$$

- **Solution：**

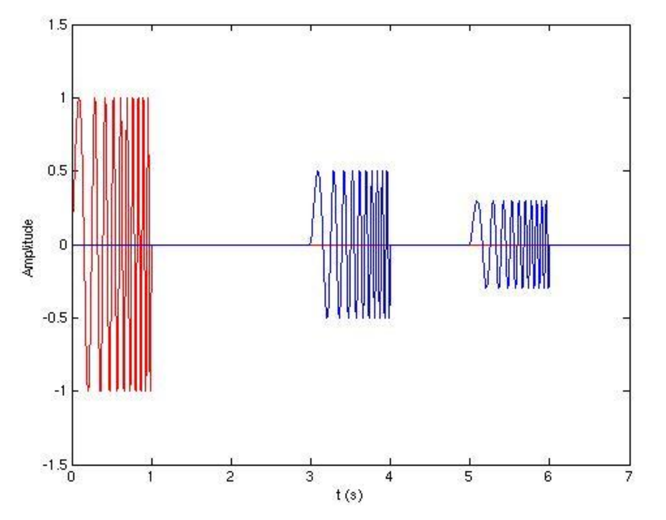


脈波$g(t)$之能量E_g=**2**

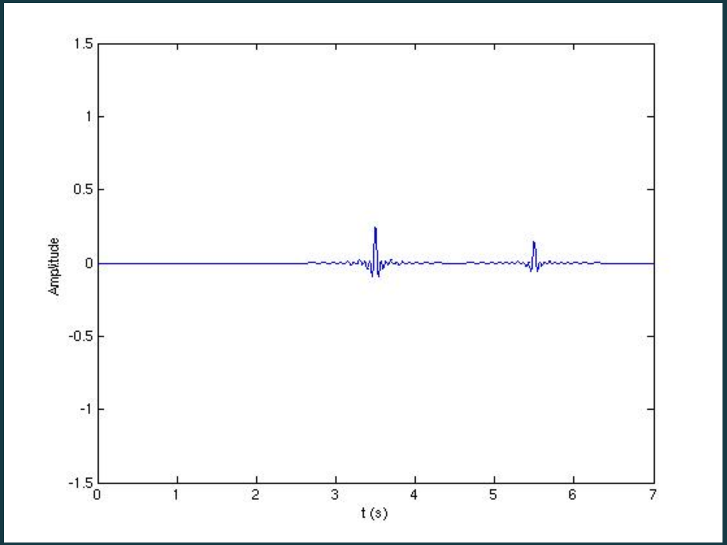
當 $t=T_b$，匹配濾波器之輸出為**2**

濾波器的脈衝響應

濾波器的輸出



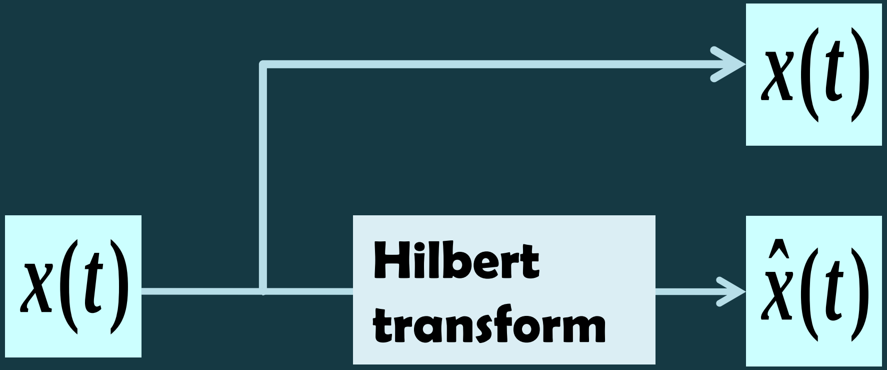
Before matched filter



After matched filter

Pulse compression

- The envelope of the compressed signal using a Hilbert transformation

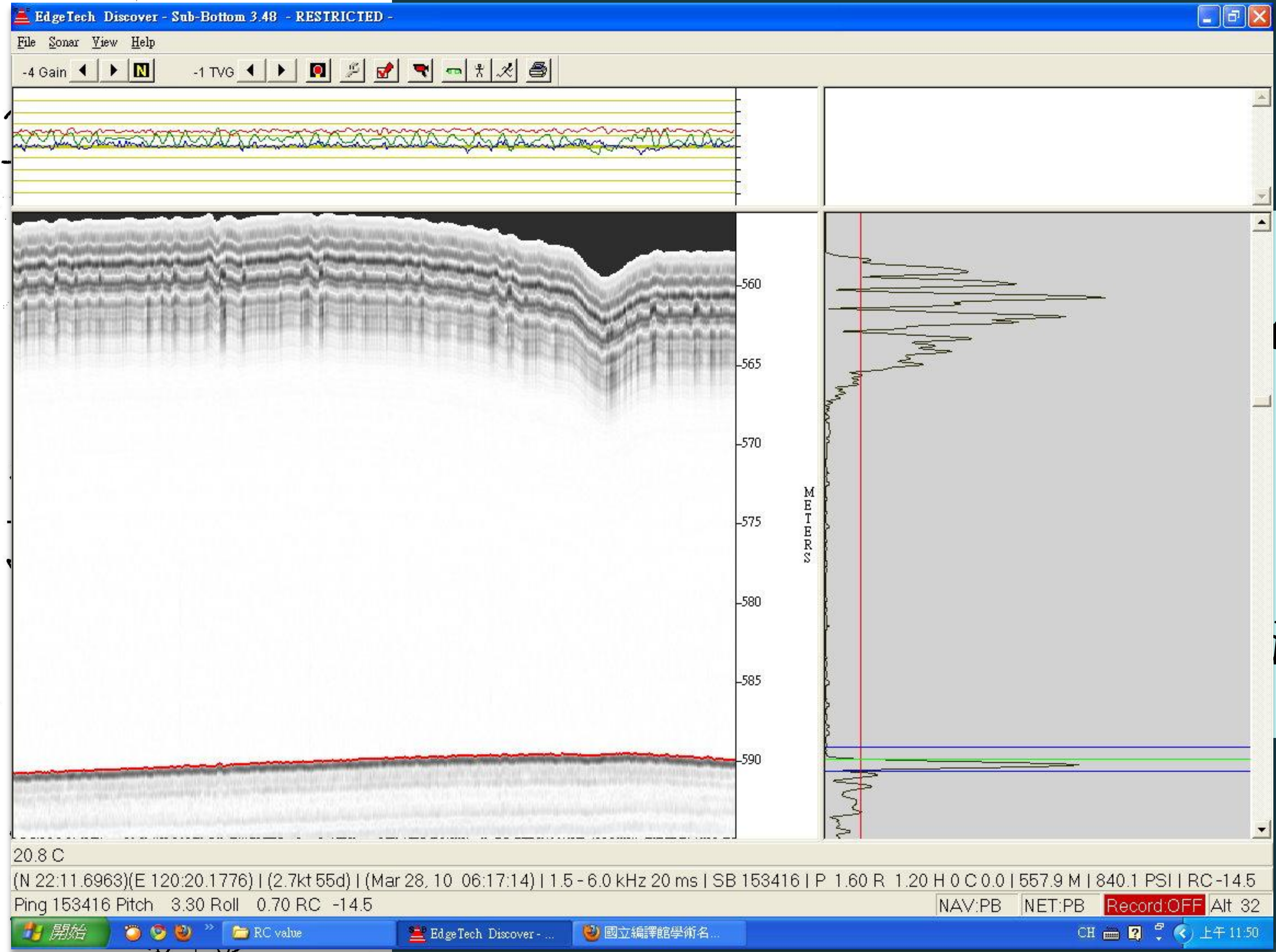


$$\hat{x}(t) = \frac{1}{\pi}\int_{-\infty}^{\infty}\frac{x(\tau)}{t-\tau}d\tau$$

$$y(t) = x(t) + j\hat{x}(t)$$

Analytic signal

$$Y(w) = X(w) + j\hat{X}(w) = 2X_p(w)$$



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20.8 C
(N 22:11.6963)(E 120:20.1776) | (2.7kt 55d) | (Mar 28, 10  06:17:14) | 1.5 - 6.0 kHz 20 ms | SB 153416 | P  1.60 R  1.20 H 0 C 0.0 | 557.9 M | 840.1 PSI | RC -14.5
Ping 153416 Pitch   3.30 Roll   0.70 RC  -14.5          NAV:PB   NET:PB   Record:OFF   Alt  32
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t)

dτ

Spherical spreading and subbottom attenuation corrections

1. Geometrical spreading losses

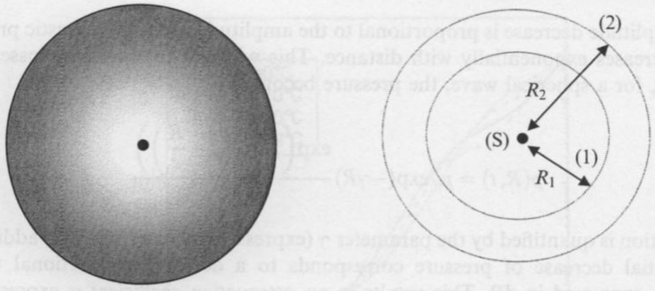


Figure 2.2. Spherical spreading: the acoustic intensity decreases with distance from the source, in inverse proportion to the sphere's surface.

$$P = I \times S = \frac{p_0^2}{2\rho c} \quad (\text{in Watts})$$

$$I = \frac{p_0^2}{2\rho c} \quad (\text{in Watts/m}^2)$$

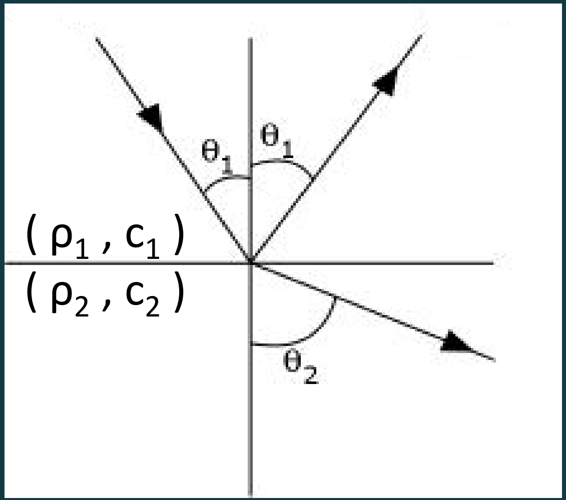
$$\frac{I_2}{I_1} = \frac{S_1}{S_2} = \left(\frac{4\pi R_1}{4\pi R_2}\right)^2 = \left(\frac{R_1}{R_2}\right)^2$$

2. Attenuation losses

$$A(f,x) = A(f,0)10^{-\frac{a(f)}{20}x}, a(f) \text{ in } dB/m$$

Sediment/water interface reflectivity calculation

$$p_i = \exp[ik(x \sin \theta_1 + z \cos \theta_1)]$$
$$p_r = R \exp[ik(x \sin \theta_1 - z \cos \theta_1)]$$
$$p_t = W \exp[ik_t(x \sin \theta_2 + z \cos \theta_2)]$$



Snell–Descartes law：

$$\frac{\sin\theta_1}{c_1} = \frac{\sin\theta_2}{c_2}$$

$$R(\theta_1) = \frac{\rho_2 c_2 \cos\theta_1 - \rho_1 c_1 \cos\theta_2}{\rho_2 c_2 \cos\theta_1 + \rho_1 c_1 \cos\theta_2}$$

$$W(\theta_1) = 1 + V(\theta_1)\ ,\ \text{if } \theta_1 < \theta_c$$

boundary conditions：

$$p_i + p_r = p_t$$

$$\frac{1}{\rho_1}\frac{\partial p_i}{\partial z} + \frac{1}{\rho_1}\frac{\partial p_r}{\partial z} = \frac{1}{\rho_2}\frac{\partial p_t}{\partial z}$$

$$R(\theta_1 = 0) = \frac{\rho_2 c_2 - \rho_1 c_1}{\rho_2 c_2 + \rho_1 c_1} = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

Acoustic density measurements of consolidating cohesive sediment beds

Experimental procedures

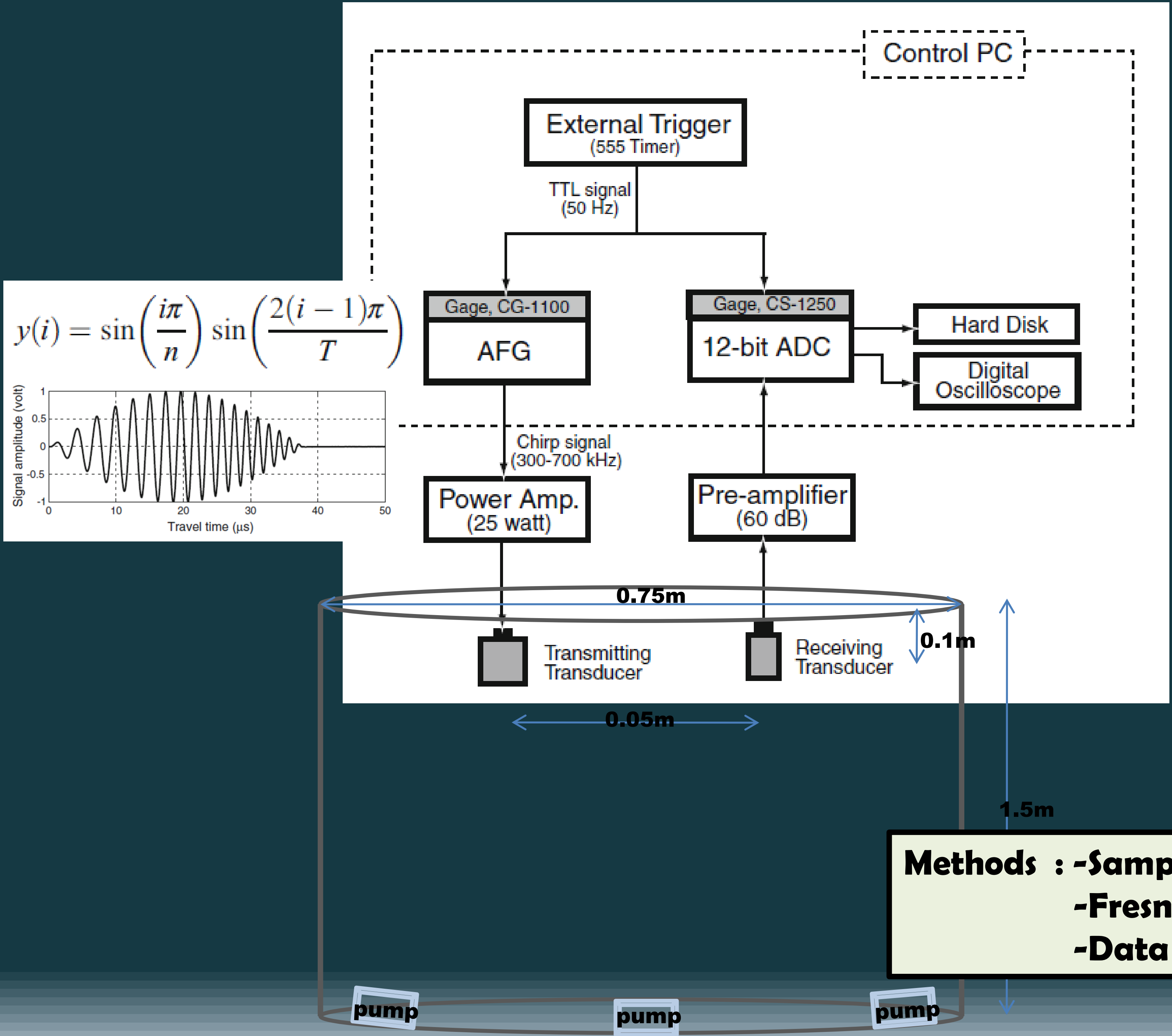
Dry kaolinite + tap water   30 days

Stop the three pumps
Initial concentration : 45 gl^{-1}
Initial height of the water column : 1.40 m

Record time : 5 , 24 , 216 , 338 , 484 , 1034 (hr)

Depth of sample extracted : 0.1 , 0.2 , 0.4 , 0.6 , 0.8 , 1.0 , 1.15 , 1.3 (m) above the bottom(dried at 103~105°C for 24 h , cooled for 2 h)

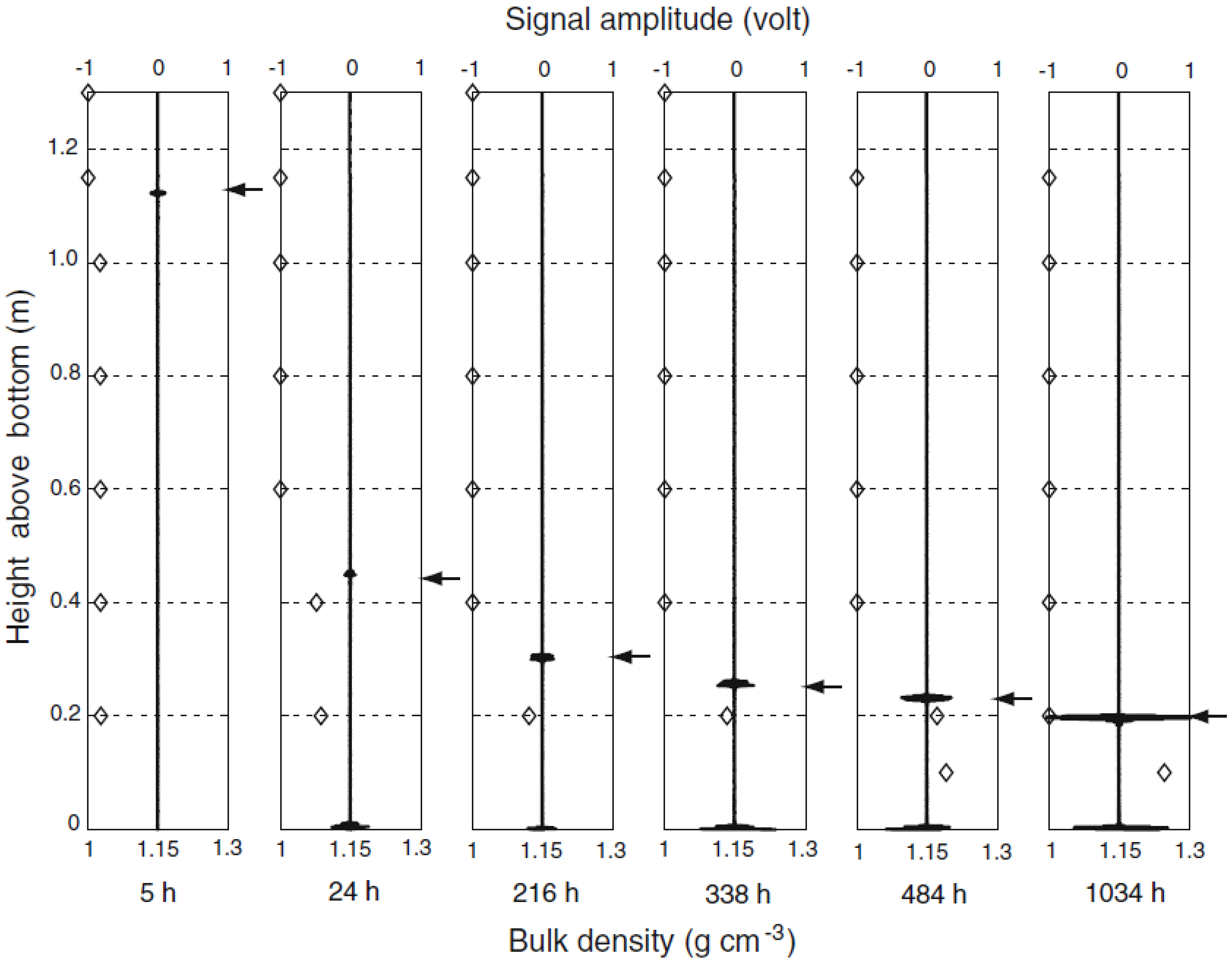
$$y(i) = \sin\left(\frac{i\pi}{n}\right)\sin\left(\frac{2(i-1)\pi}{T}\right)$$



Methods : -Sample

-Fresnel law

-Data processing


Signal amplitude (volt)
-1
0
1
Height above bottom (m)
1.2
1.0
0.8
0.6
0.4
0.2
0
1
1.15
1.3
5 h
24 h
216 h
338 h
484 h
1034 h
Bulk density (g cm -3)

Bulk density :

$$\rho_b = \frac{M_s}{V_t} + \rho_w(1-\varphi_s)$$

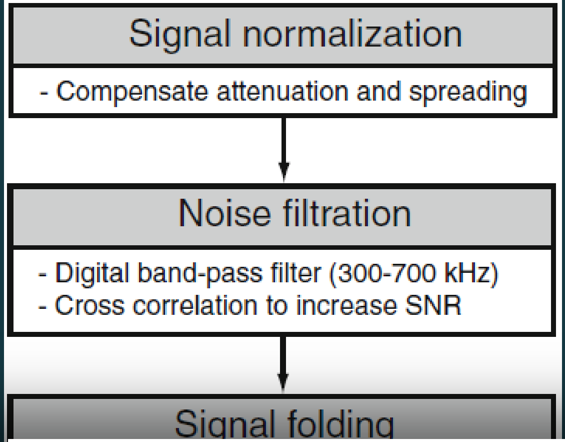
M_s : dry sediment mass
V_t : volumes of the sediment sample
Φ_s : $M_s/v_t/\rho_s$
ρ_w : water density

Fresnel law :

$$P(z,t) = R(\theta,z,t)\frac{P_0\sqrt{B(\theta)}}{2z}e^{-2\alpha z}$$

$$R = \frac{\rho_2 c_2 - \rho_1 c_1}{\rho_2 c_2 + \rho_1 c_1}$$

P : proportional to the measured signal
P_o : source level (reference to 1 m)
R : reflection coefficient
B : beam pattern factor (Gaussian distribution with -3dB at beam width 2.3°)
θ : beam angle
α : sound attenuation coefficient
z : the height above the bed
t : duration for consolidation



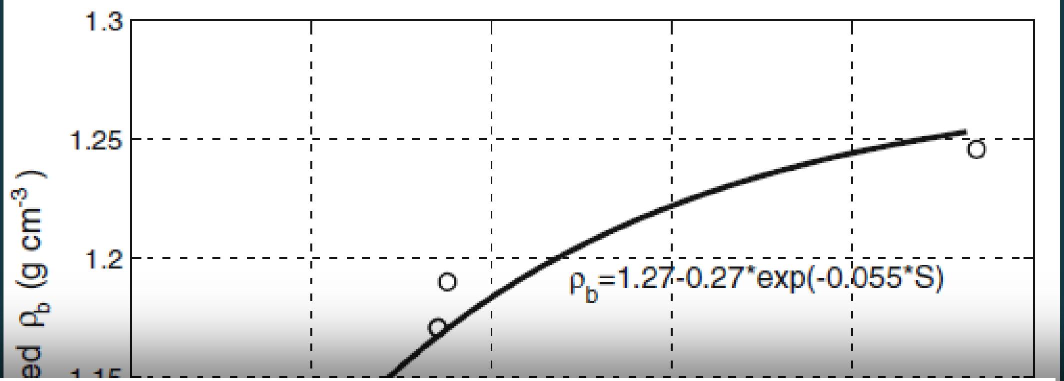
Signal normalization

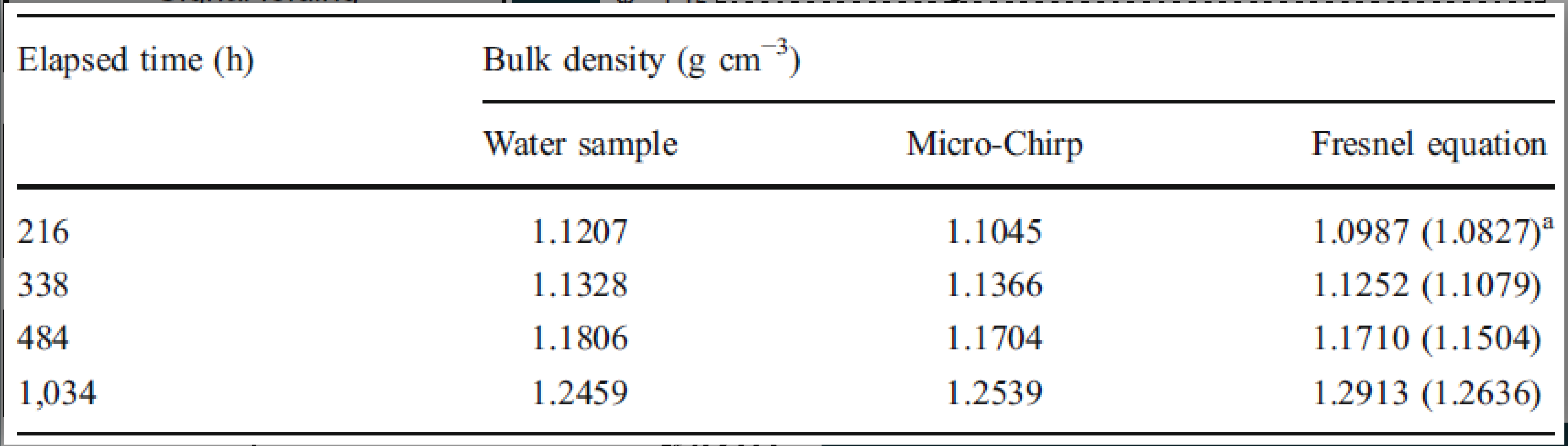
- Compensate attenuation and spreading

Noise filtration

- Digital band-pass filter (300-700 kHz)
- Cross correlation to increase SNR

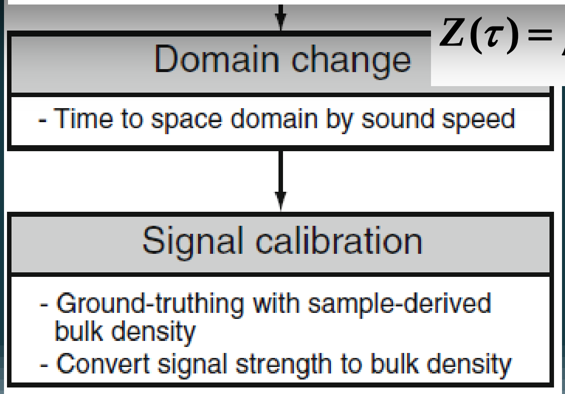
Signal folding





Elapsed time (h)	Bulk density (g cm^{-3})		
	Water sample	Micro-Chirp	Fresnel equation
216	1.1207	1.1045	1.0987 (1.0827)[a]
338	1.1328	1.1366	1.1252 (1.1079)
484	1.1806	1.1704	1.1710 (1.1504)
1,034	1.2459	1.2539	1.2913 (1.2636)

$$Z(\tau)=\rho_b(\tau)c=\int_0^{\tau}\frac{dZ(t)}{dt}dt$$



Domain change

- Time to space domain by sound speed

Signal calibration

- Ground-truthing with sample-derived bulk density
- Convert signal strength to bulk density

Relationship between processed signal strength and sample derived bulk density

Conclusion

- The matched filter is the optimal linear filter for maximizing the signal to noise ratio in the presence of additive stochastic noise

- The envelope of the compressed signal is the amplitude of the return at the peak

- The measured reflection coefficient of the top layer can be calibrated by means of in-situ sediment samples