Event Detection

Hsiao-Lung Chan, Ph.D.
Dept Electrical Engineering
Chang Gung University, Taiwan
chanhl@mail.cgu.edu.tw

Derivative

- Two-point difference

$$y(n) = \frac{1}{T}[x(n) - x(n-1)]$$

- Three-point difference

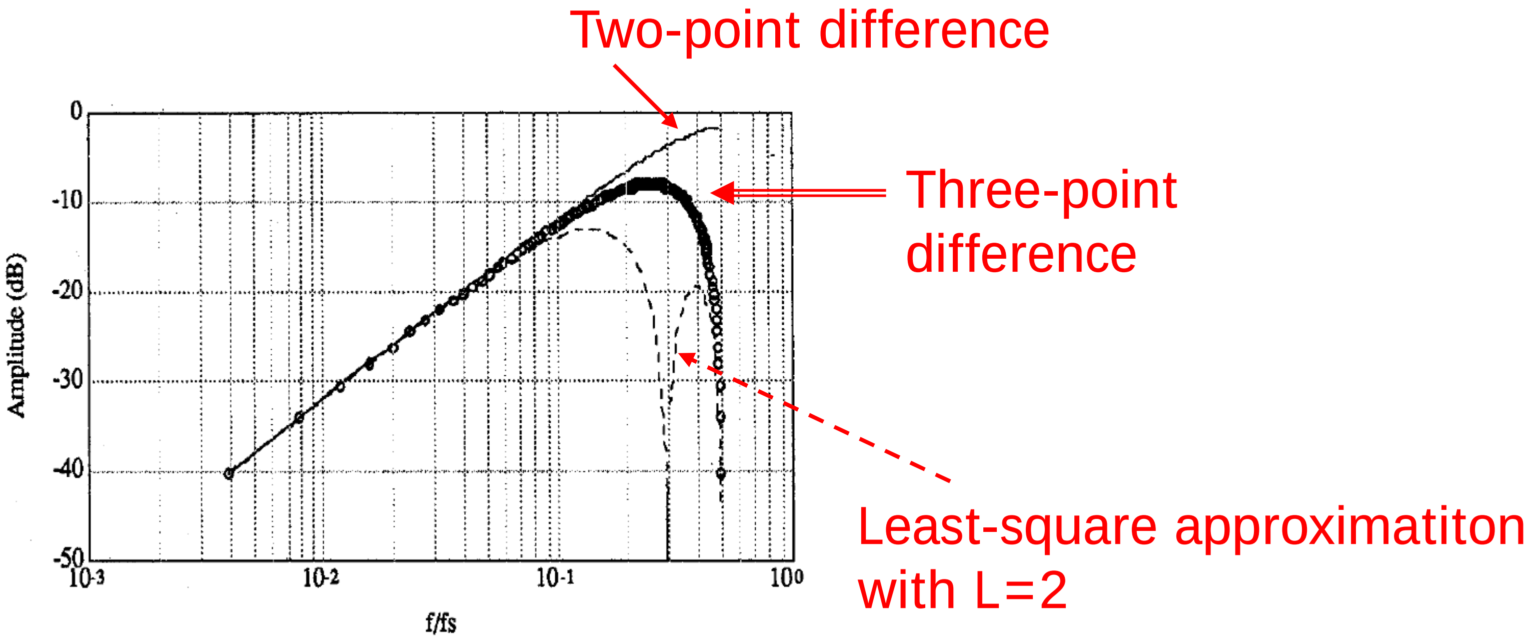
$$y(n) = \frac{1}{2T}[x(n) - x(n-2)]$$

- Five-point difference

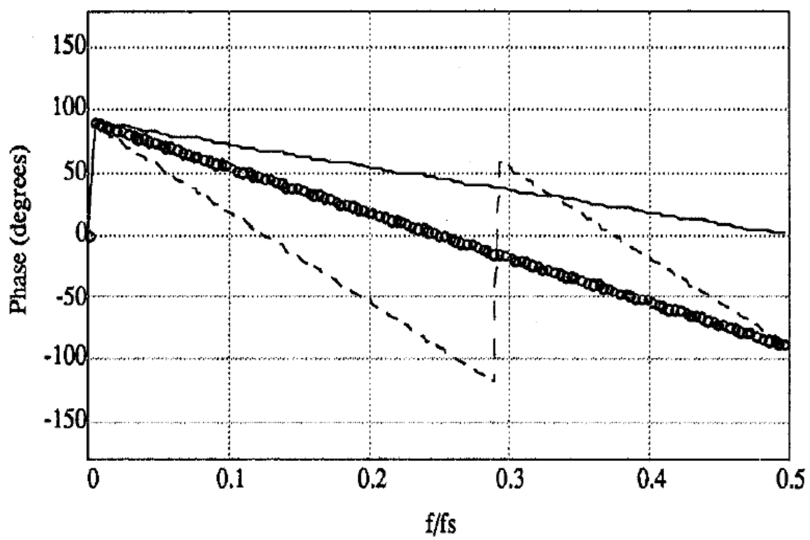
$$y(n) = \frac{1}{10T}[2x(n) + x(n-1) - x(n-3) - 2x(n-4)]$$

Derivative based on least-square polynominal approximation

L	Tap weights
2	$\frac{1}{10T}(2, 1, 0, -1, -2)$
3	$\frac{1}{28T}(3, 2, 1, 0, -1, -2, -3)$
4	$\frac{1}{60T}(4, 3, 2, 1, 0, -1, -2, -3, -4)$
5	$\frac{1}{110T}(5, 4, 3, 2, 1, 0, -1, -2, -3, -4, -5)$


Two-point difference
Three-point difference
Least-square approximatiton with L=2
Amplitude (dB)
0
-10
-20
-30
-40
-50
10-3
10-2
10-1
100
f/fs

(a)

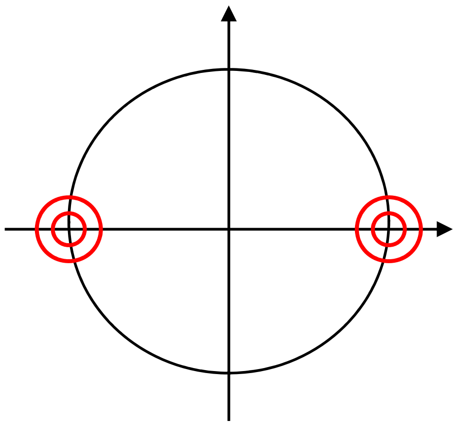

Phase (degrees)
150
100
50
0
-50
-100
-150
0
0.1
0.2
0.3
0.4
0.5
f/fs

(b)

Second derivative

$$H(z) = (1 - z^{-2})(1 - z^{-2}) = 1 - 2z^{-2} + z^{-4}$$

$$y(n) = x(n) - 2x(n-2) + x(n-4)$$



Exercise

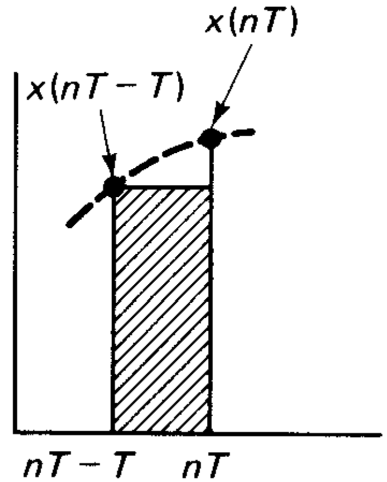
- Please derive 1st and 2nd derivatives of the filtered ECG (after notch filter).

Integrator

- Rectangular integration

$$y(n) = y(n-1) + T \cdot x(n-1)$$

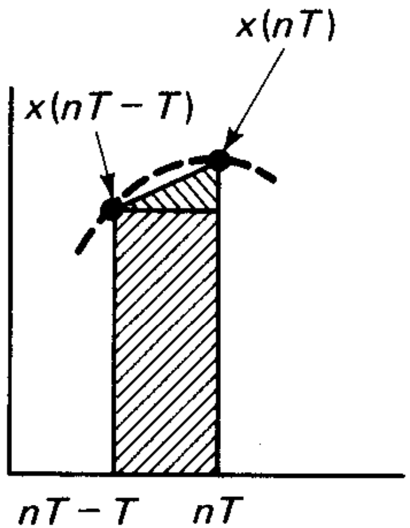
Need high sampling rate to reduce integration error



- Trapezoidal integration

$$y(n) = y(n-1) + T \cdot x(n-1) + \frac{T}{2}[x(n) - x(n-1)]$$

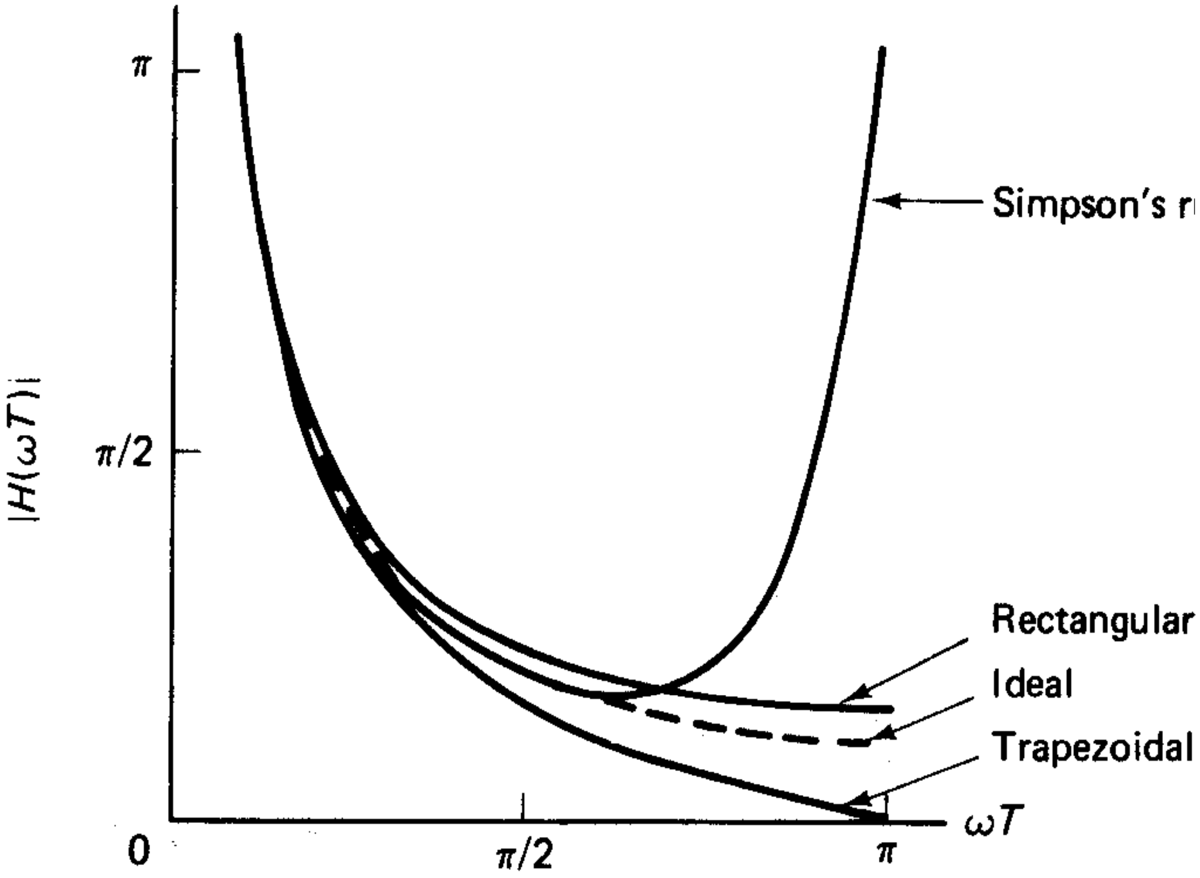
$$= y(n-1) + \frac{T}{2}[x(n) + x(n-1)]$$

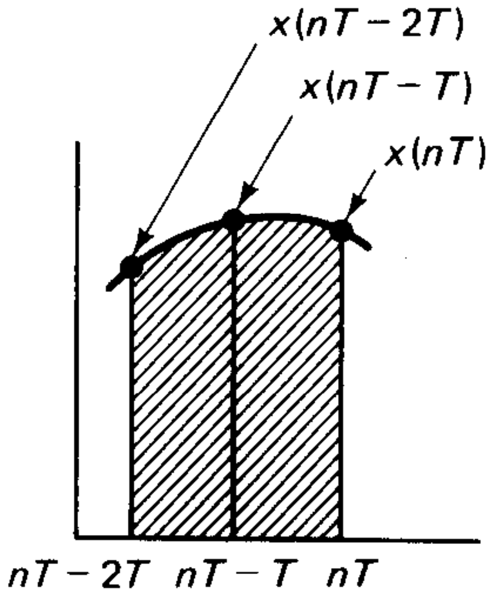


From WJ. Tompkins, JG. Webster, Design of Microcomputer-Based Medical Instrumentation, Prentice-Hall, 1981.

Simpson's rule integration

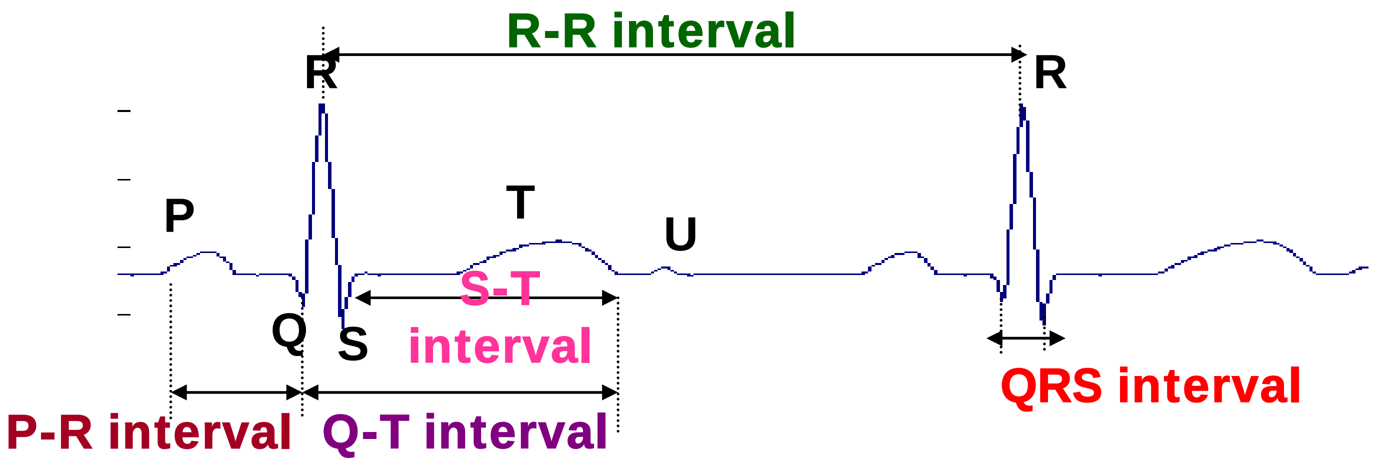
$$y(n) = y(n-2) + \frac{T}{3}[x(n) + 4x(n-1) + x(n-2)]$$





From WJ. Tompkins, JG. Webster, Design of Microcomputer-Based Medical Instrumentation, Prentice-Hall, 1981.

ECG characteristics



P wave : **Atrial depolarization**
QRS complex : **Ventricular depolarization**
T wave : **Ventricular repolarization**
U wave : **Slow repolarization of ventricular muscle**
R-R : **Heart period**
P-R : **Conduction delay in the AV-node**
Q-T, S-T : **Ventricular repolarization time**

Power spectrum of ECG

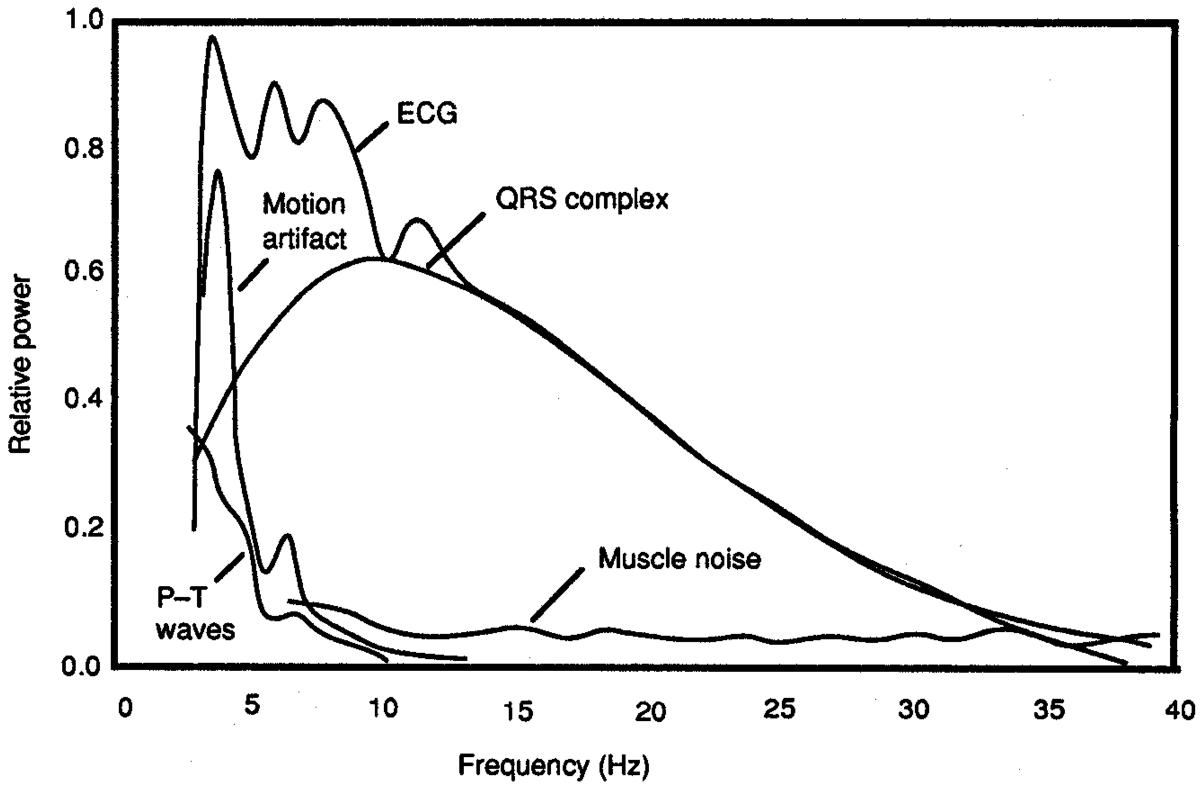
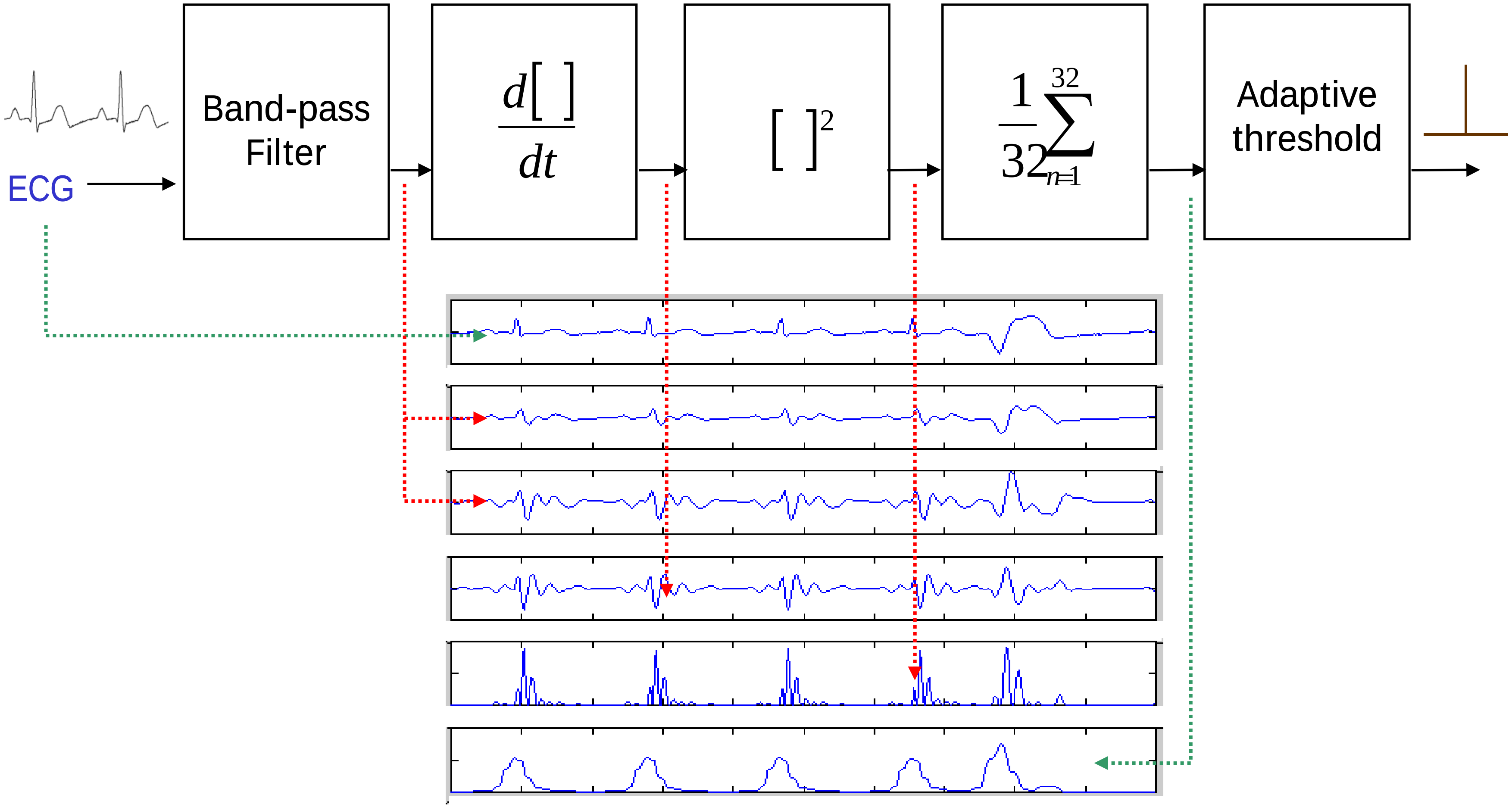


Figure 12.1 Relative power spectra of QRS complex, P and T waves, muscle noise and motion artifacts based on an average of 150 beats.

Pan-Tompkins QRS detection



Signal-to-noise ratio of QRS complex

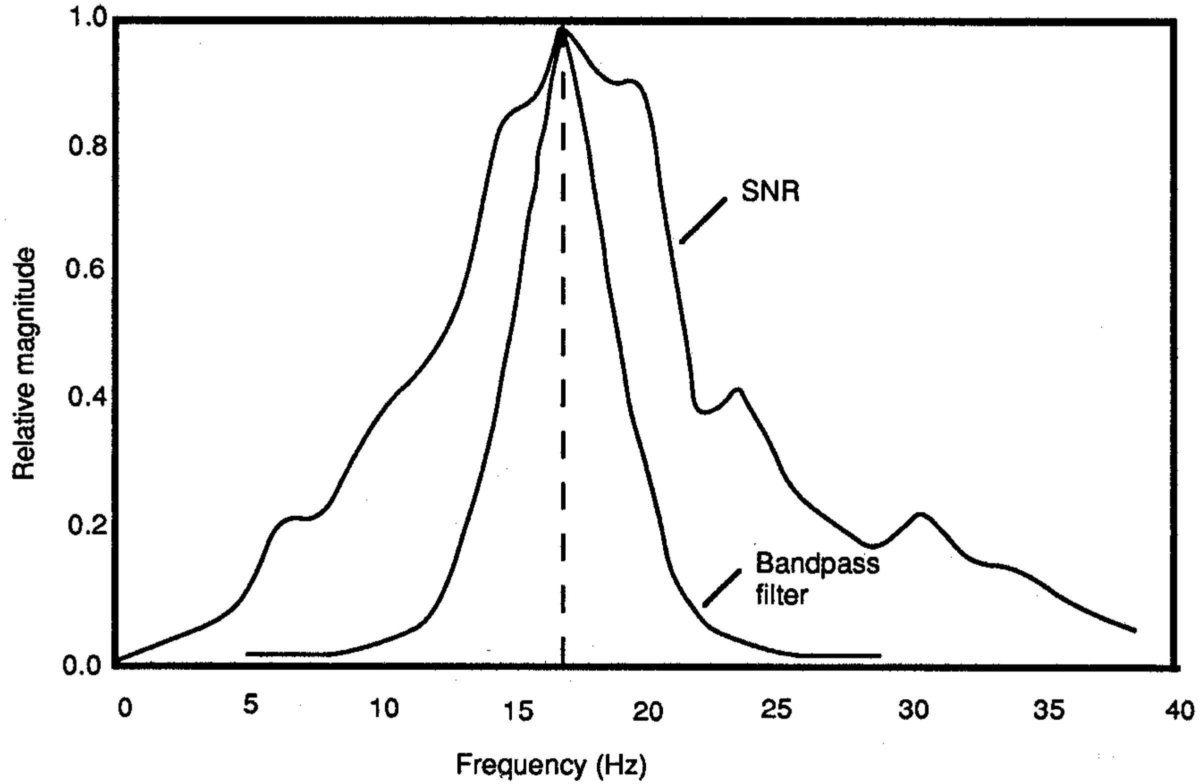


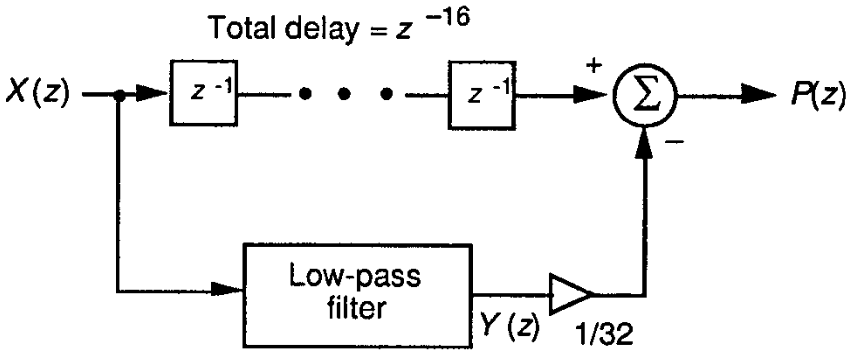
Figure 12.2 Plots of the signal-to-noise ratio (SNR) of the QRS complex referenced to all other signal noise based on 3875 heart beats. The optimal bandpass filter for a cardiotachometer maximizes the SNR.

Bandpass filter design of P-T method

Lowpass Filter

$$H(z) = \frac{(1-z^{-6})^2}{(1-z^{-1})^2}$$

$$y(n) = 2y(n-1) - y(n-2) + x(n) - 2x(n-6) + x(n-12)$$

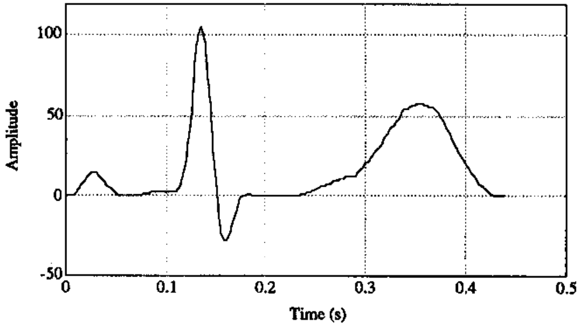


Highpass Filter

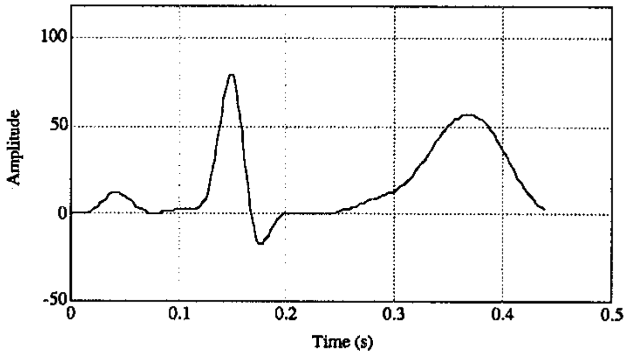
$$H_{lp}(z) = \frac{1-z^{-32}}{1-z^{-1}}$$

$$H_{hp}(z) = z^{-16} - \frac{H_{lp}(z)}{32} = z^{-16} - \frac{1}{32}\frac{1-z^{-32}}{1-z^{-1}}$$

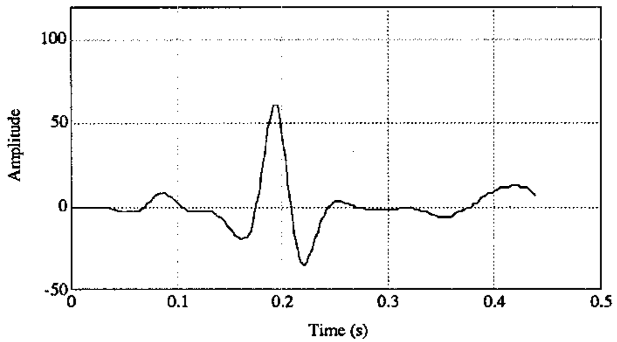
$$y(n) = x(n-16) - \frac{1}{32}[y(n-1) + x(n) - x(n-32)]$$

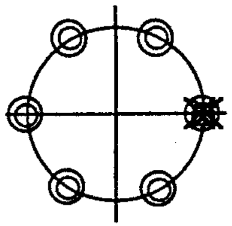


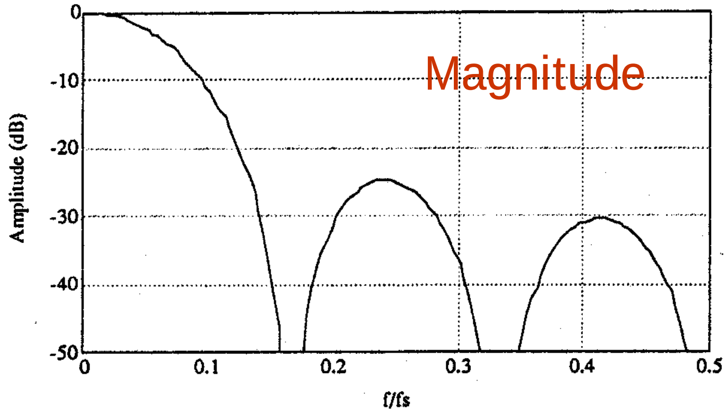
Lowpass filtering

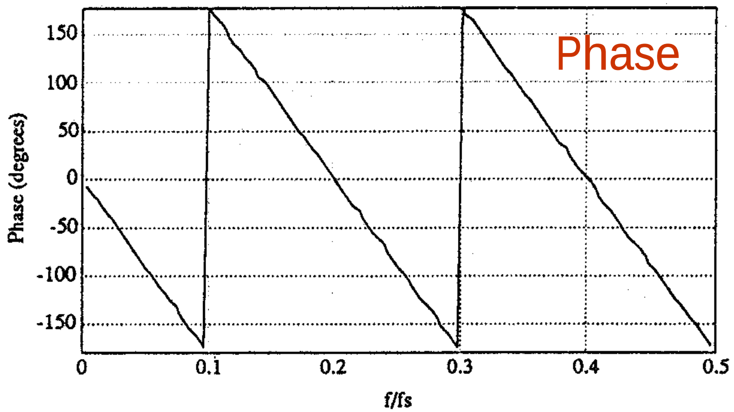


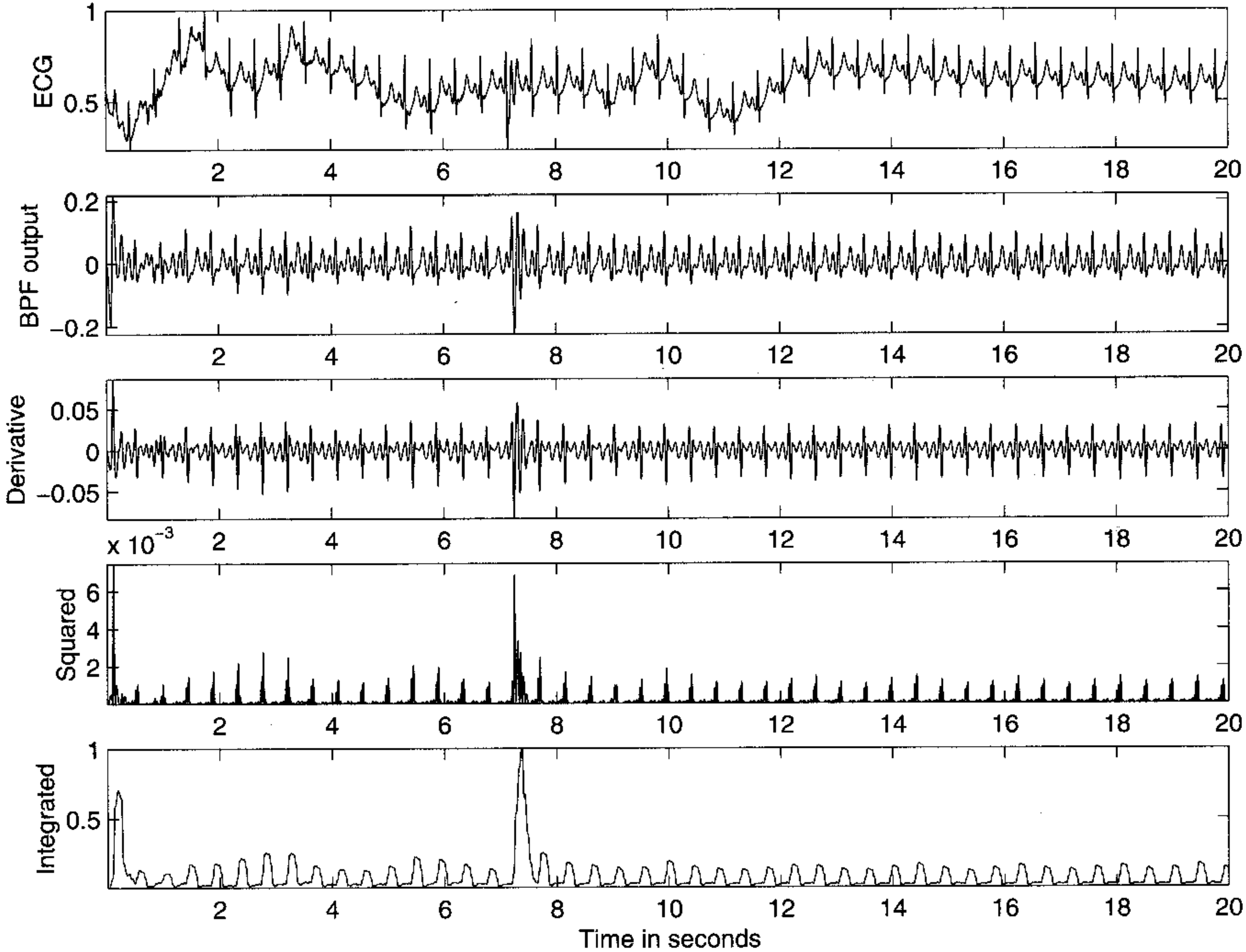
Highass filtering










ECG
BPF output
Derivative
x 10^-3
Squared
Integrated
Time in seconds

Adaptive threshold of P-T method

Threshold set and updated

If PEAKI is the signal peak

$$\mathrm{SPKI} = 0.125\ \mathrm{PEAKI} + 0.875\ \mathrm{SPKI}$$

If PEAKI is the noise peak

$$\mathrm{NPKI} = 0.125\ \mathrm{PEAKI} + 0.875\ \mathrm{NPKI}$$

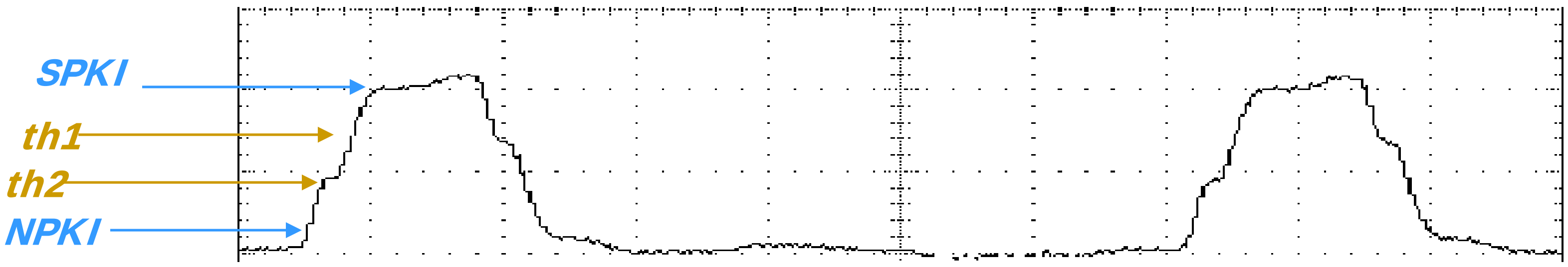
Two thresholds

$$\mathrm{THRESHOLD\ 1} = \mathrm{NPKI} + 0.25\,(\mathrm{SPKI} - \mathrm{NPKI})$$

$$\mathrm{THRESHOLD\ 2} = 0.5\ \mathrm{THRESHOLD\ 1}$$

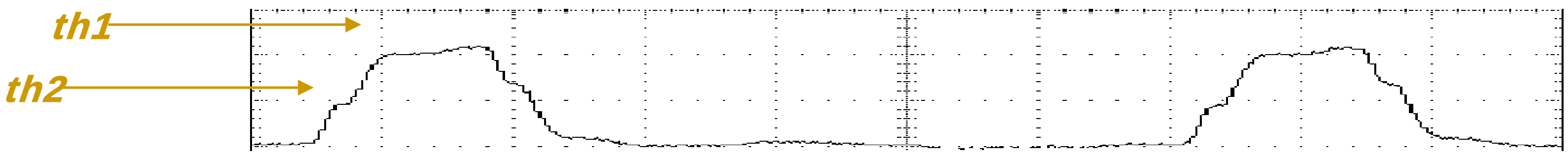
Adaptive threshold (Cont.)

- QRS complex is found using threshold 1



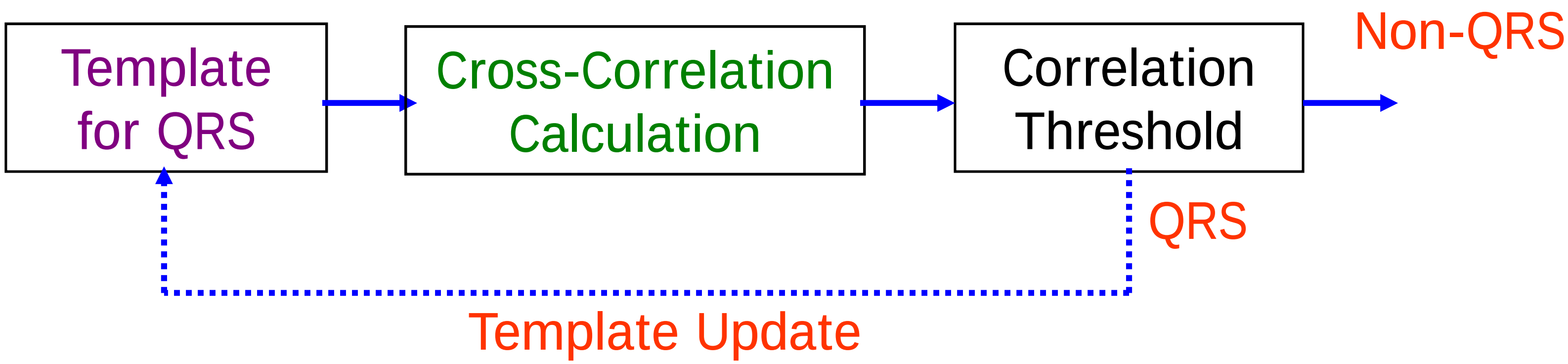
$$\mathrm{SPKI} = 0.125\mathrm{PEAKI} + 0.875\ \mathrm{SPKI}$$

- QRS complex is found using threshold 2



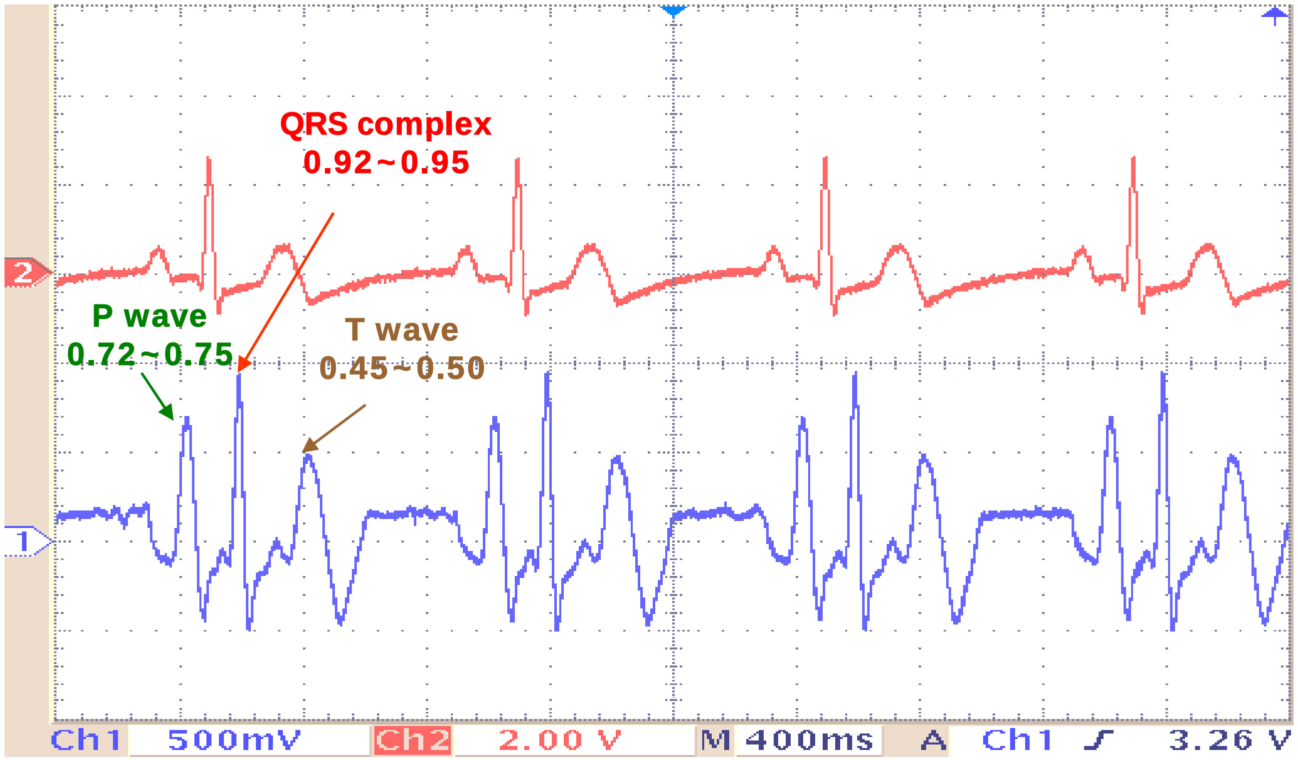
$$\mathrm{SPKI} = 0.25\mathrm{PEAKI} + 0.75\ \mathrm{SPKI}$$

QRS detection by template match

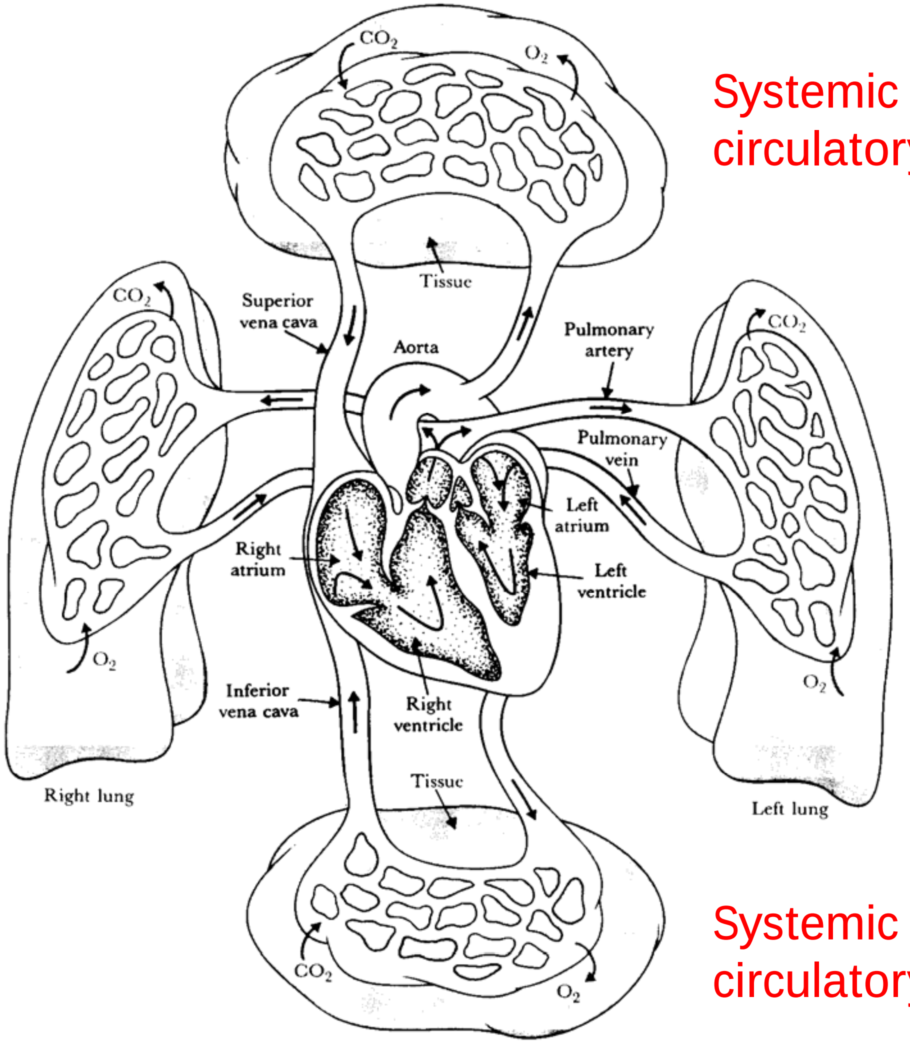


$$r_{xy} = \frac{\sum_{i=1}^{N}(x_i - m_x)(y_i - m_y)}{\sqrt{\sum_{i=1}^{N}(x_i - m_x)^2}\sqrt{\sum_{i=1}^{N}(y_i - m_y)^2}}$$

Template match (cont.)



Circulatory system

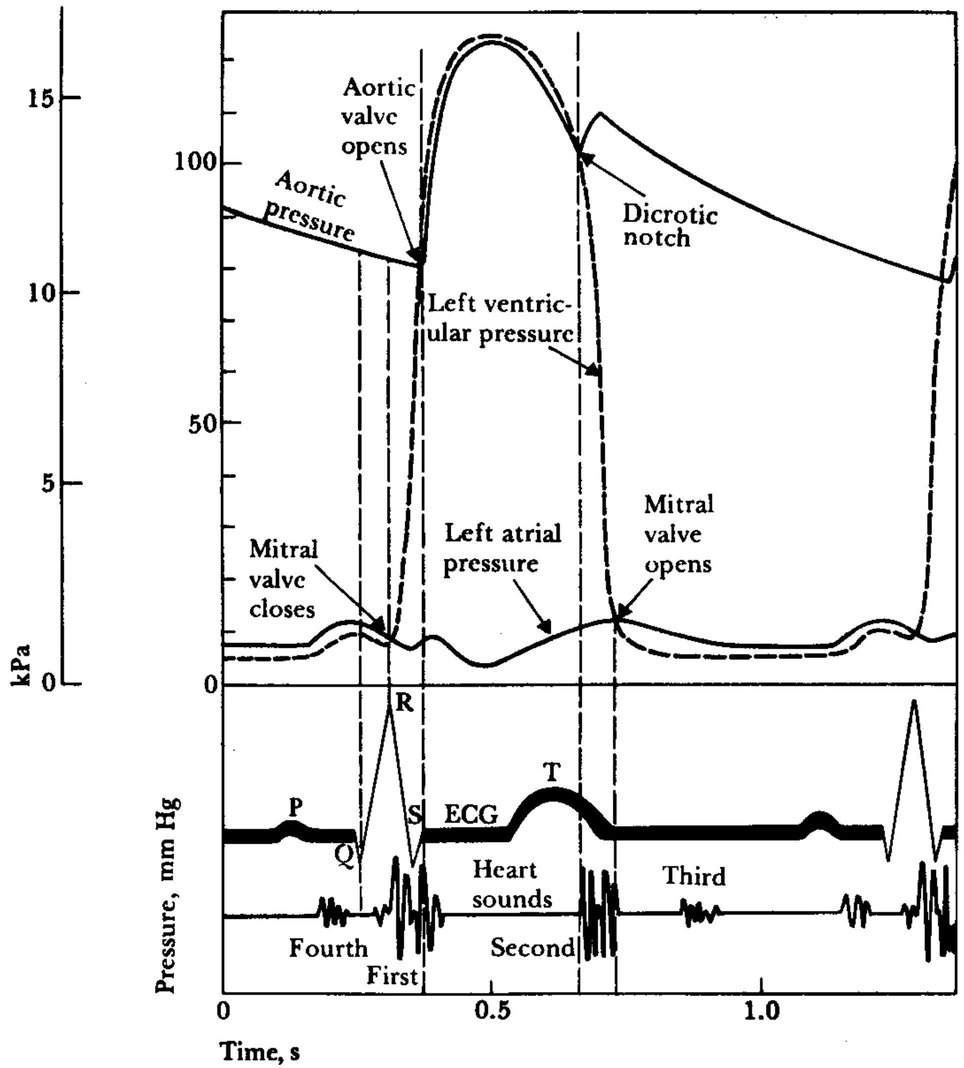


Systemic circulatory system

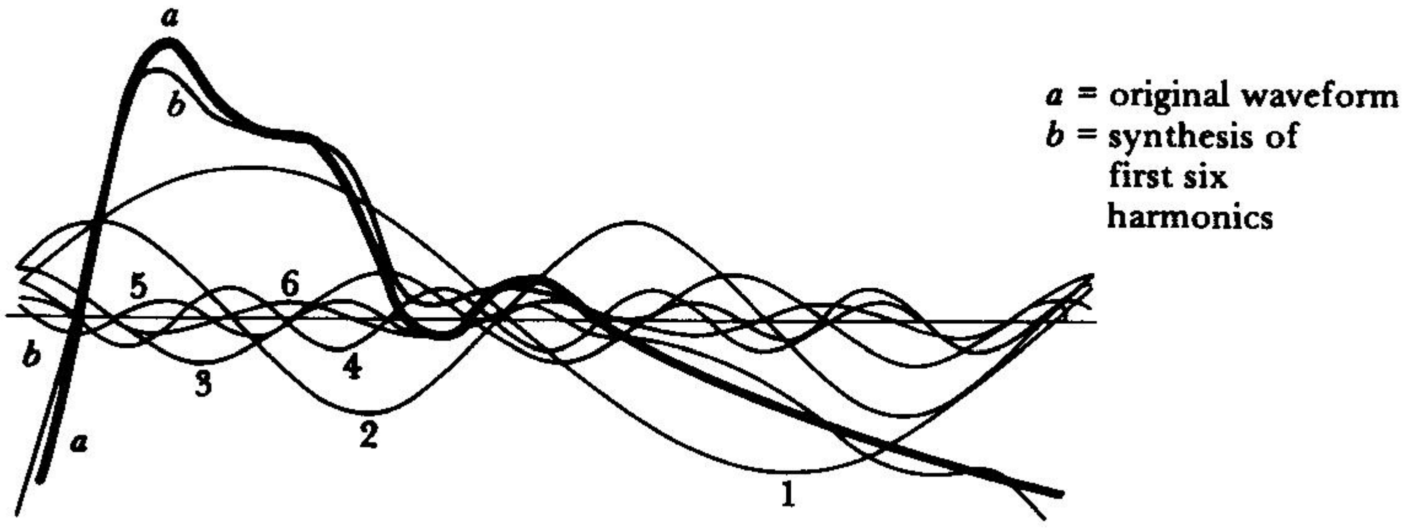
Pulmonary circulatory system

Systemic circulatory system

Cardiac cycle

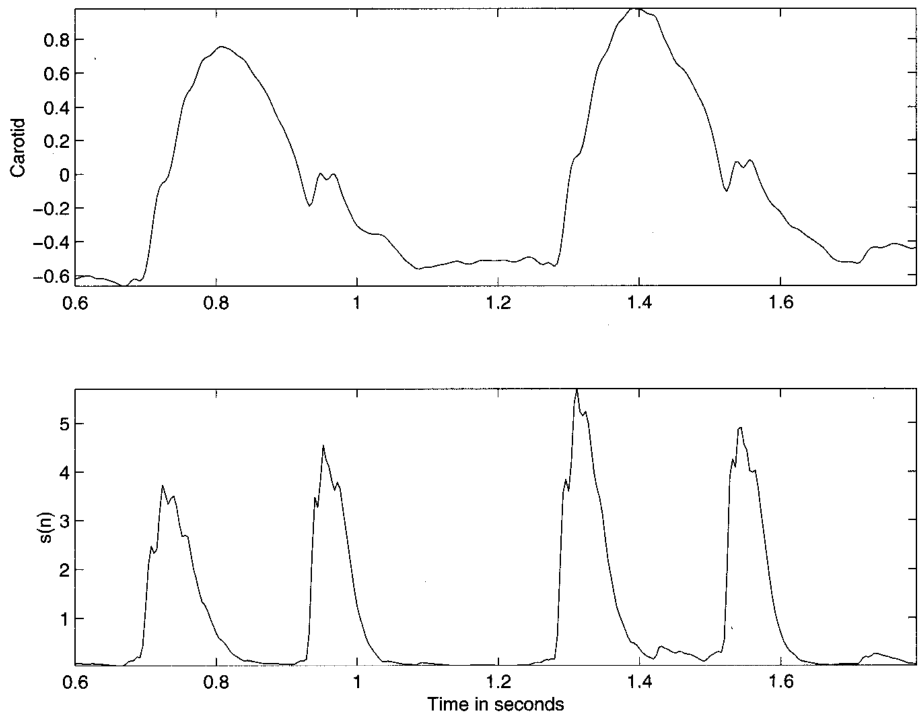


Harmonic analysis of blood-pressure waveform



Harmonic	Amplitude (%)
1	100
2	63.2
3	29.6
4	22.2
5	14.8
6	11.8

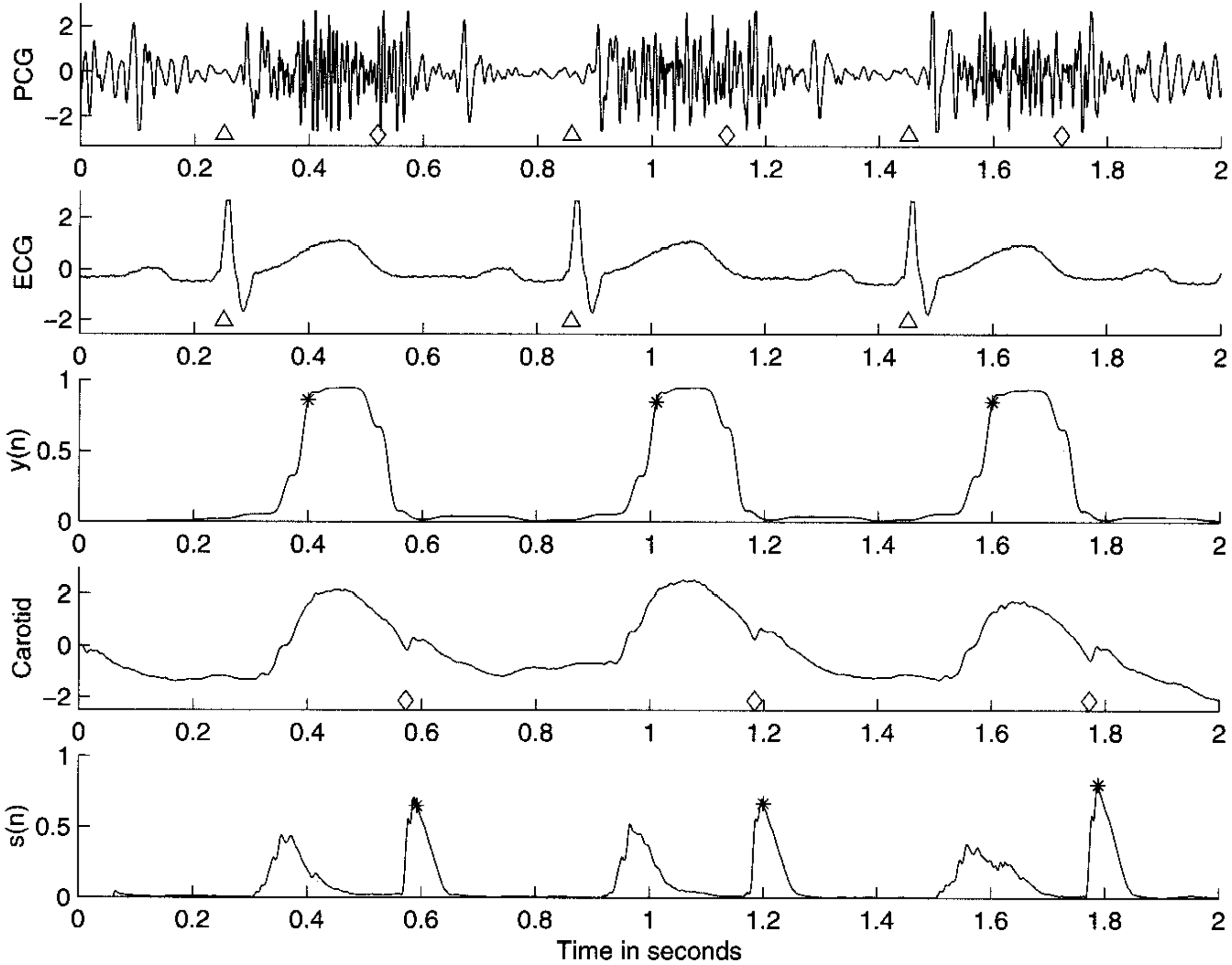
Detection of dicrotic Notch in carotid pulse



$$p(n) = 2y(n-2) - y(n-1) - 2y(n) - y(n+1) + 2y(n+2)$$

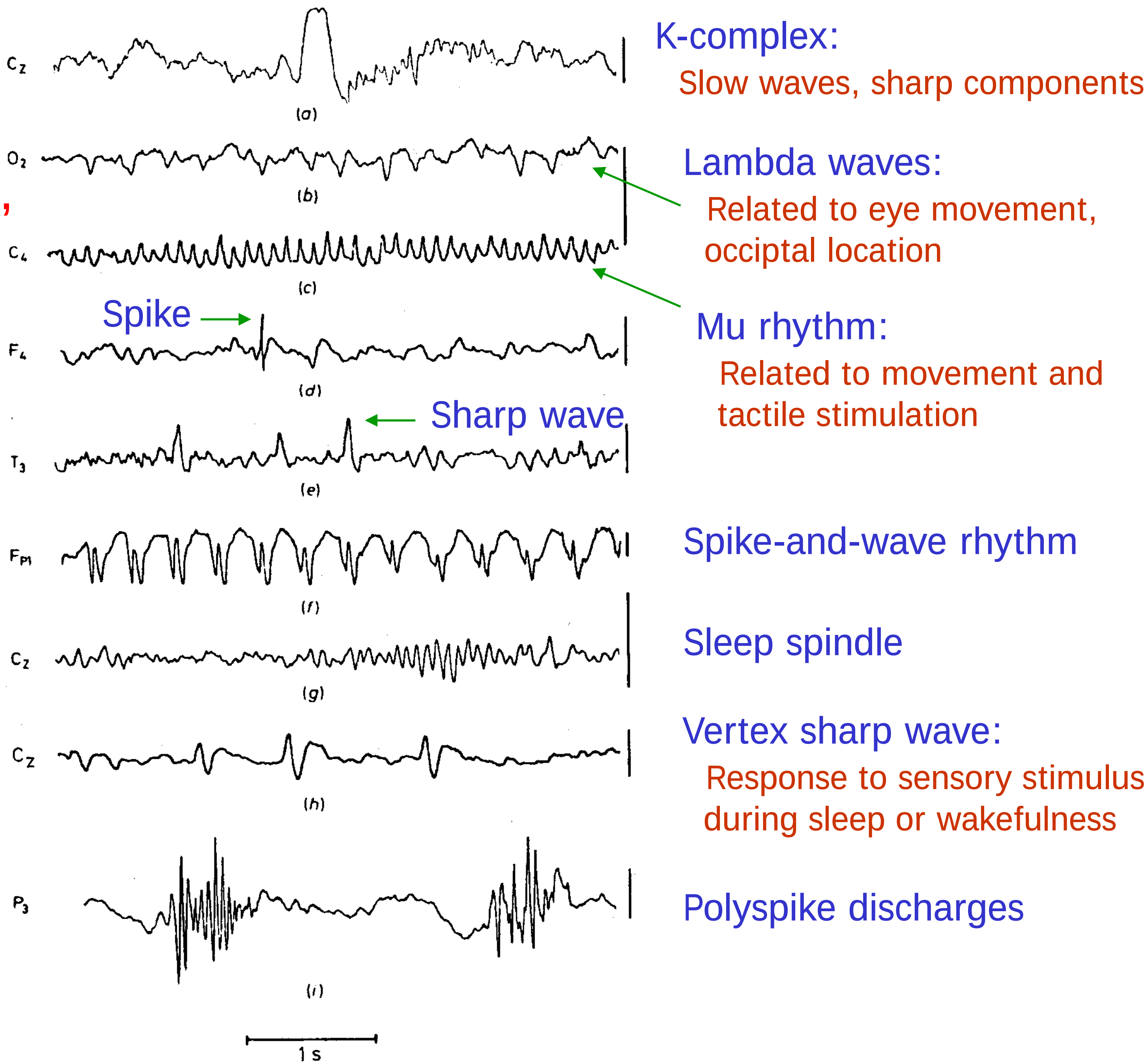
$$s(n) = \sum_{k=1}^{M} p^2(n-k+1)(M-k+1)$$

Detect QRS and carotid points

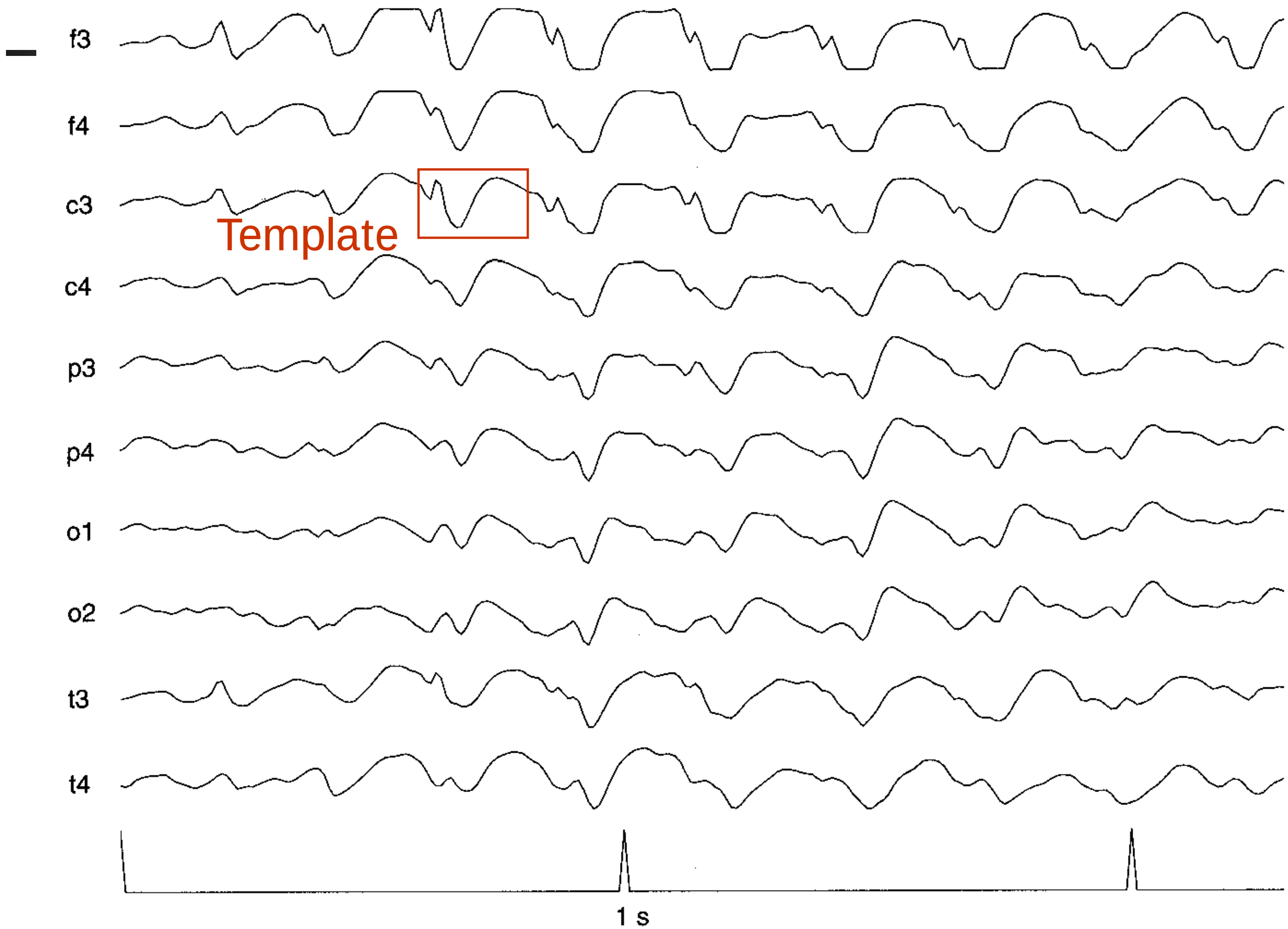


Data retrieved by pcg3read.m

EEG rhythms, waves, transients

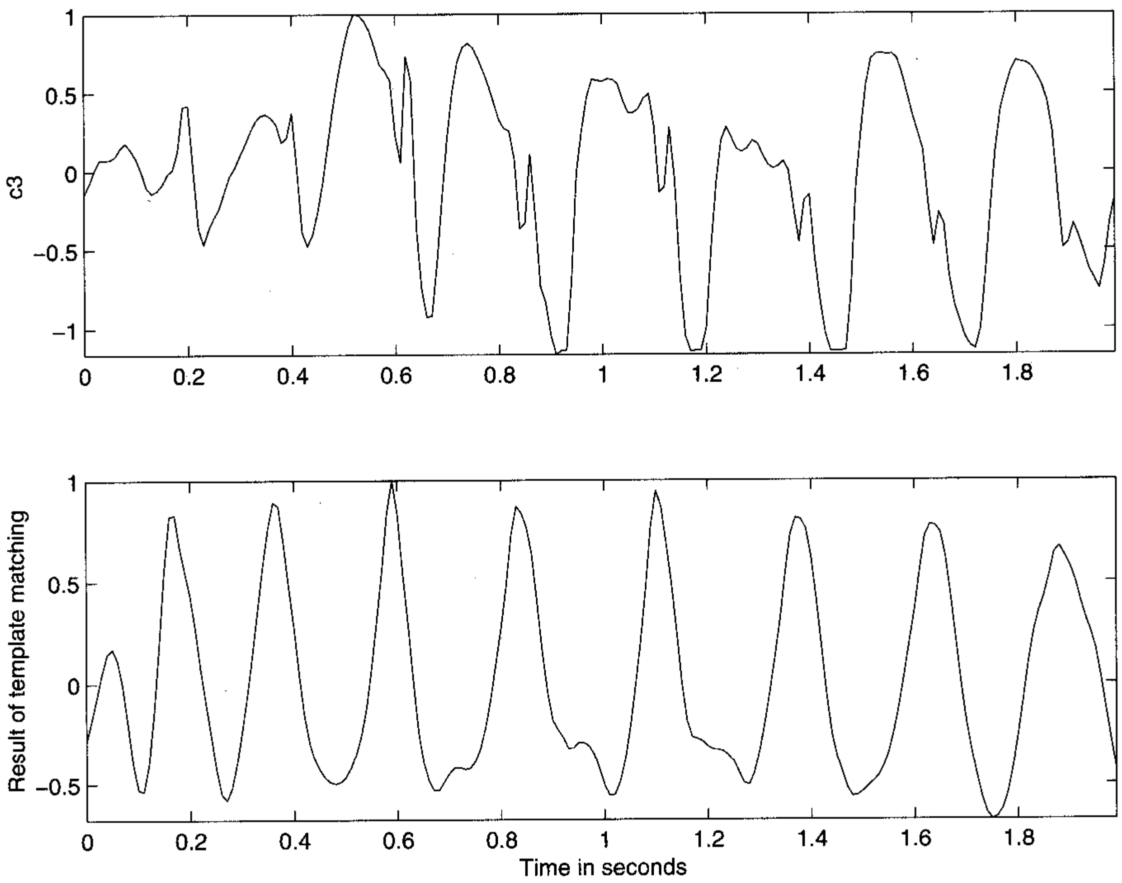


Spike-and-wave complexes



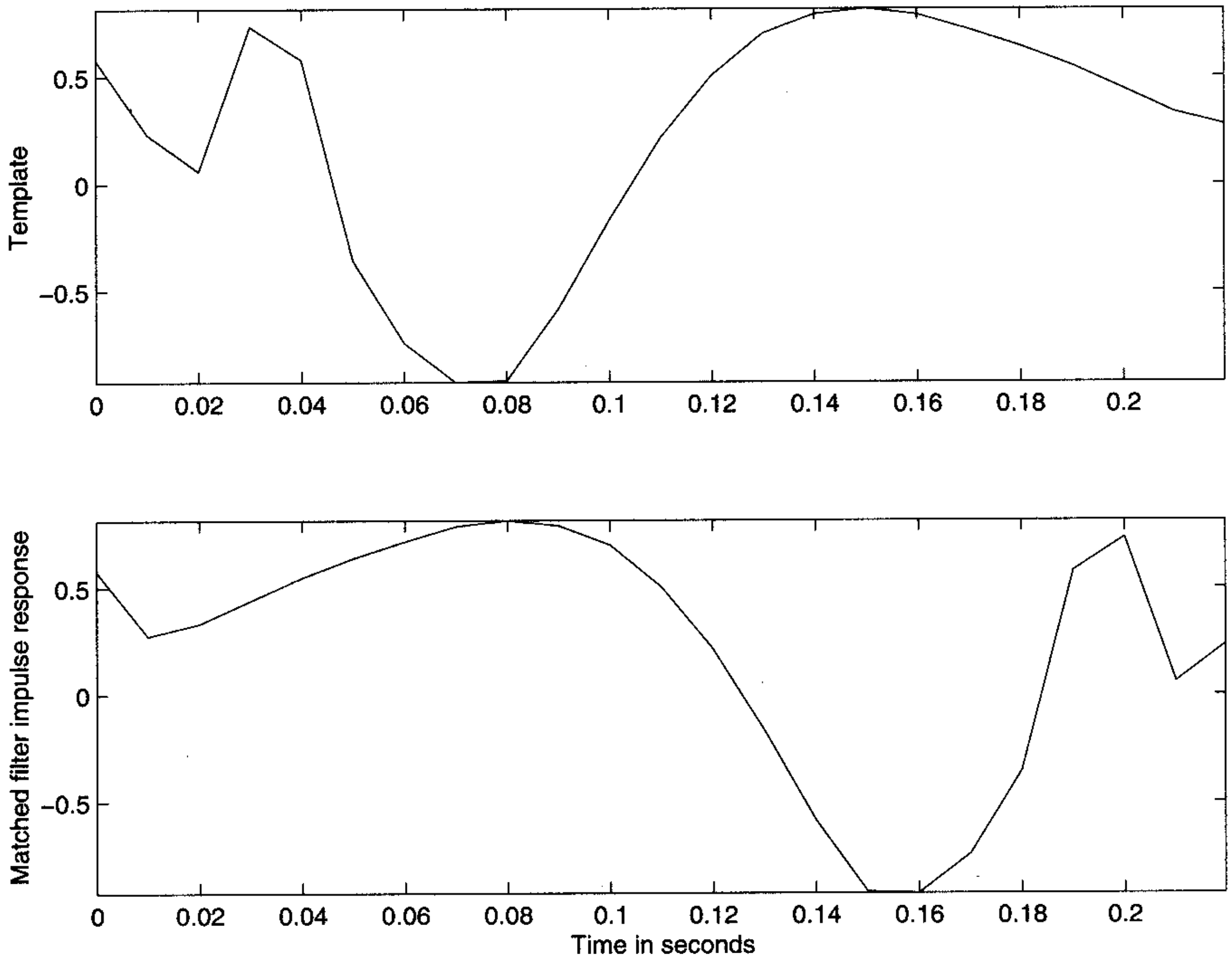
Data from eeg_spike.mat

Spike-and-wave detection by template match

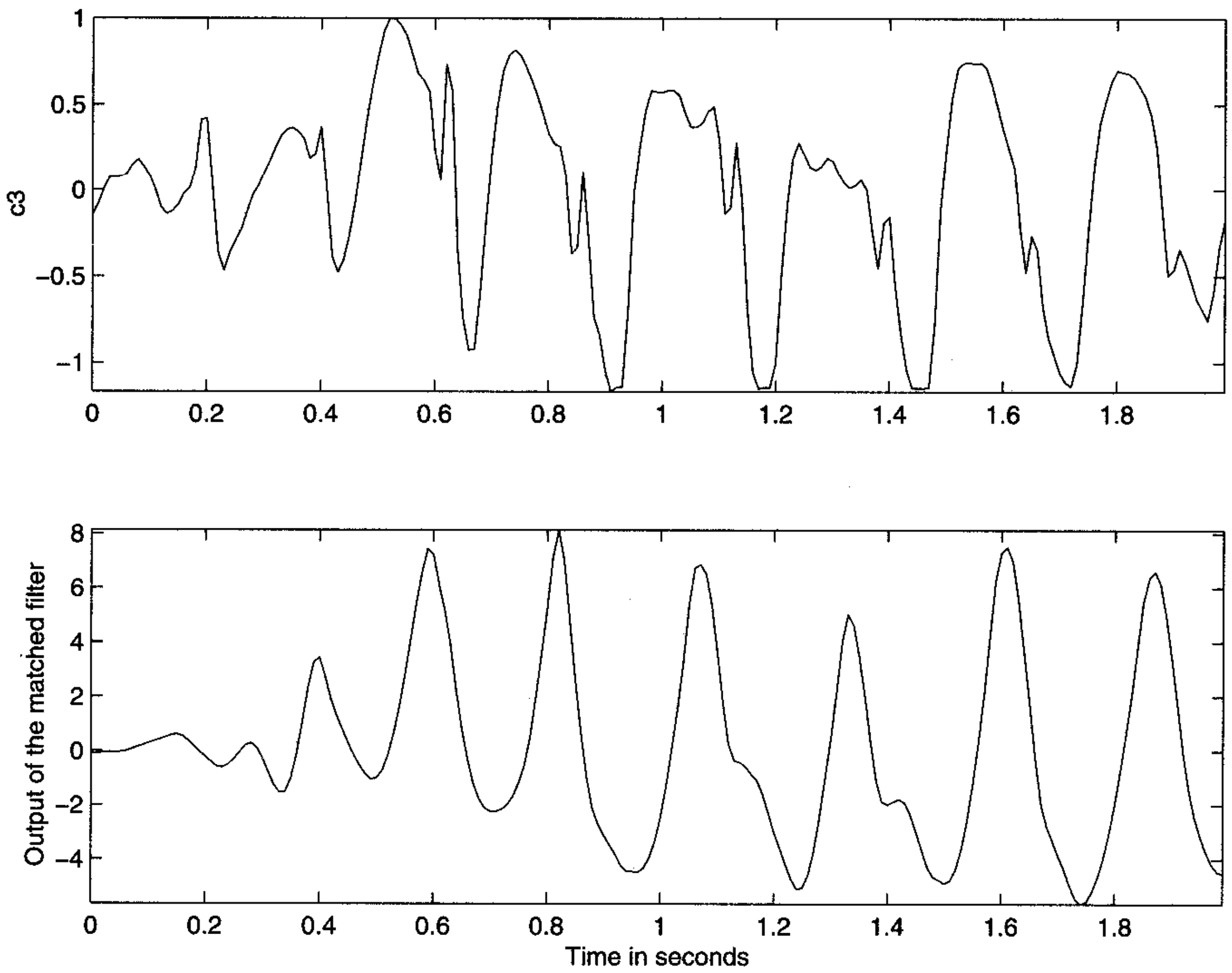


$$\gamma_{xy}(f) = \frac{\sum_{n=0}^{N-1} x(n) y(n)}{\left[\sum_{n=0}^{N-1} x^2(n) \sum_{n=0}^{N-1} y^2(n)\right]^{1/2}}$$

Spike-and-wave detection by matched filter



Matched filter (cont.)



Reference

- WJ. Tompkins, Biomedical Digital Signal Processing, Prentice-Hall, 1993.
- R. Rangayyan, Biomedical Signal Analysis, John Wiely & Sons, 2002.
- John G. Webster, Medical Instrumentation, application and design, 3rd Ed., Houghton Mifflin, 2000.