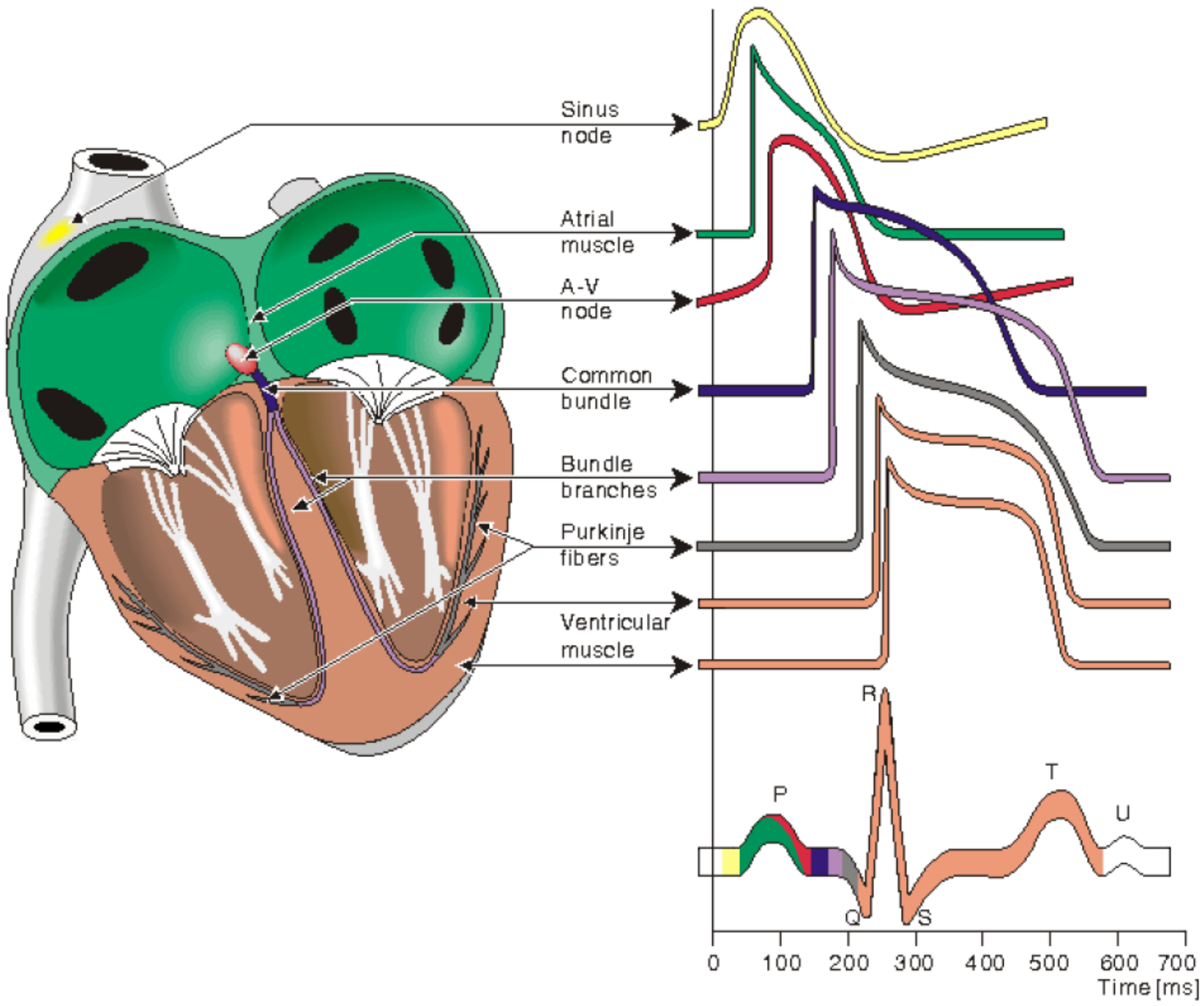
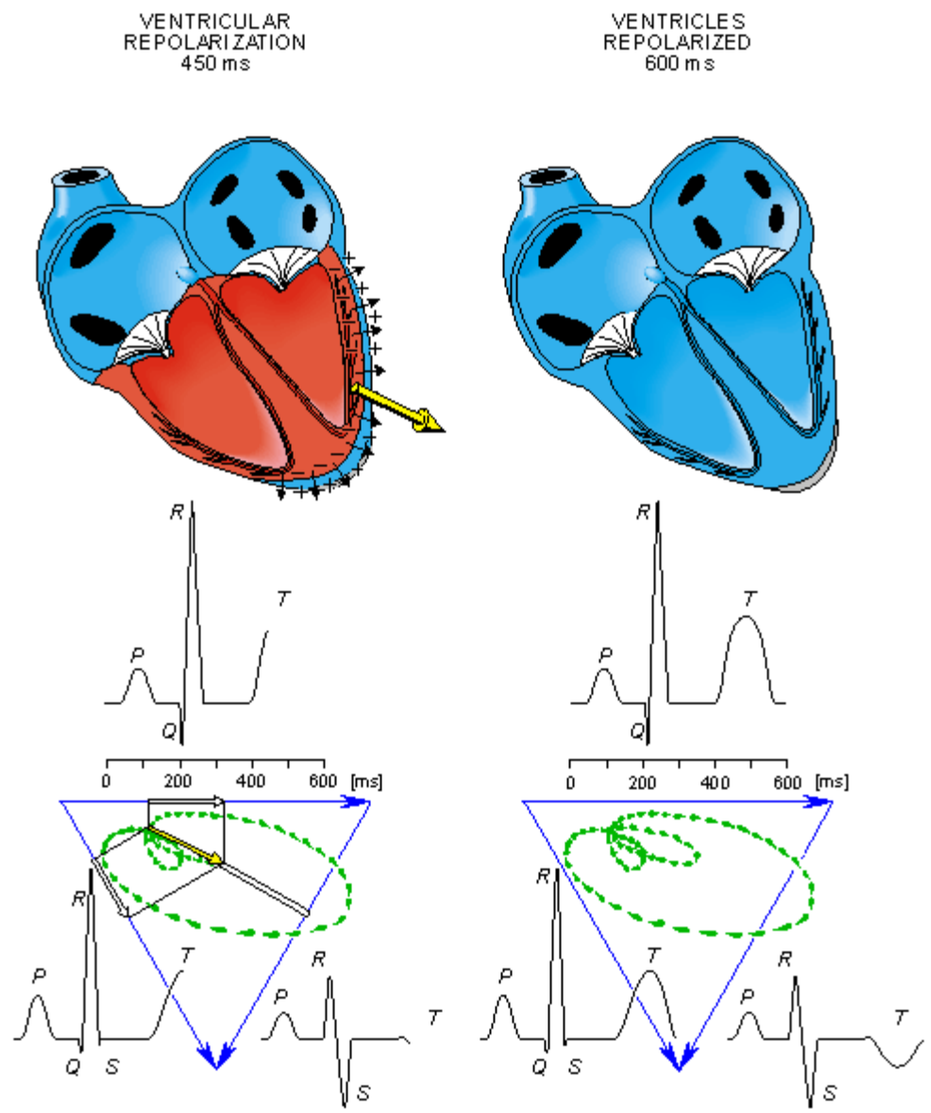
Lab 2:

ECG Circuits and Signal Processing

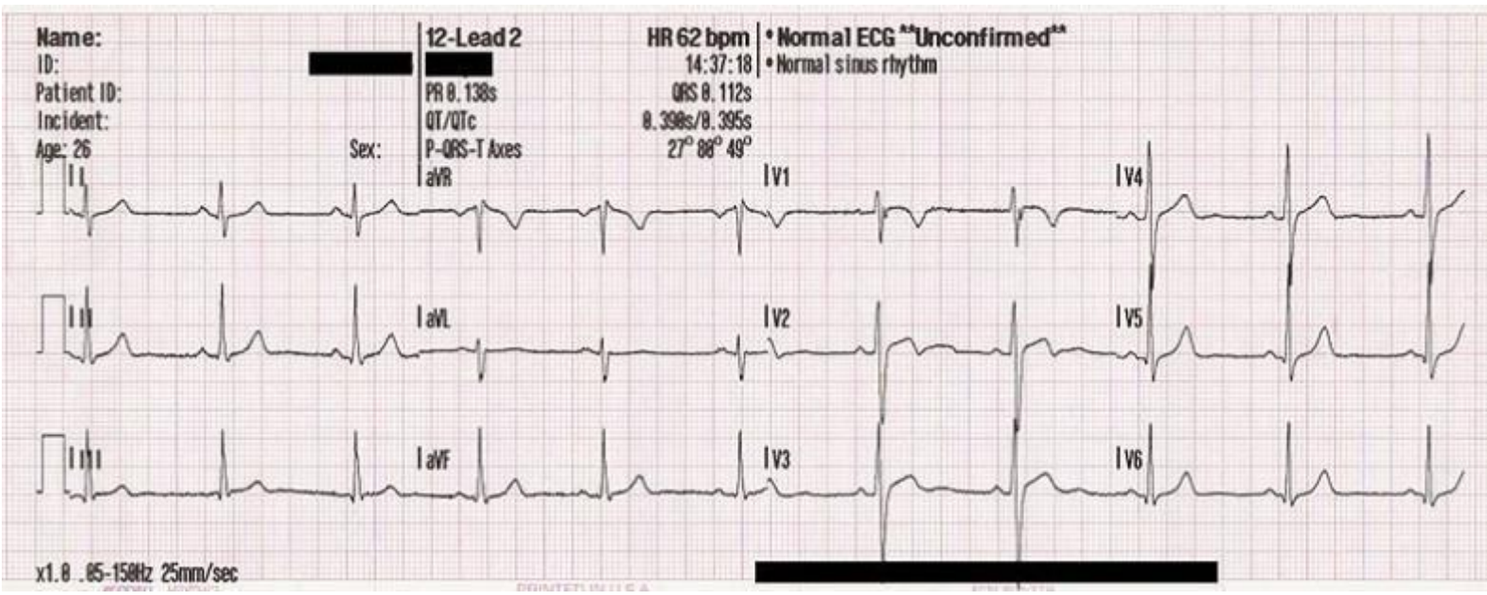
Formation of the ECG Signal(1/2)

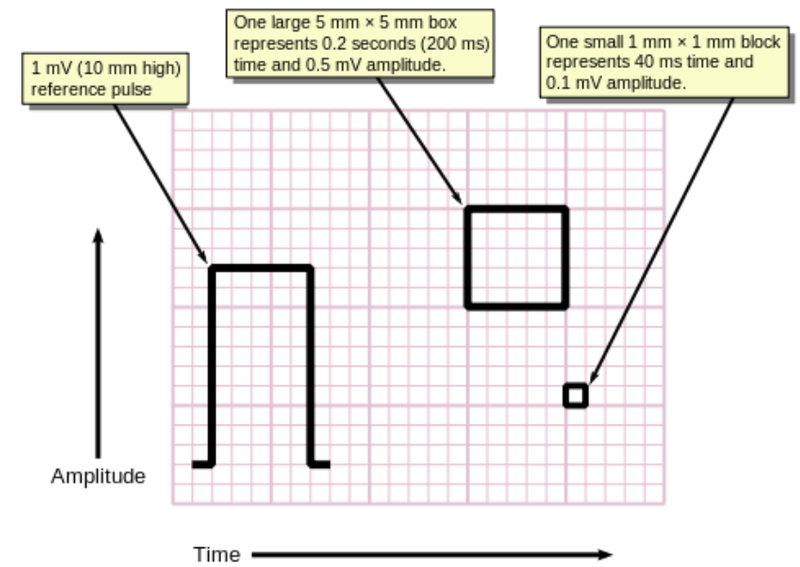


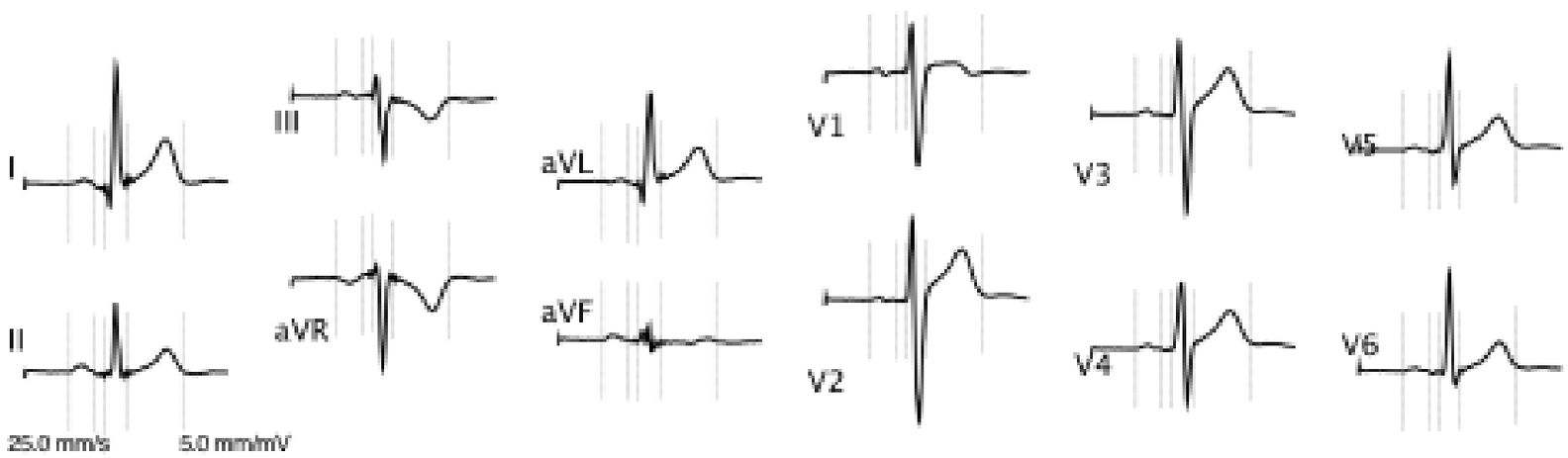
Formation of the ECG Signal(2/2)



12-lead ECG

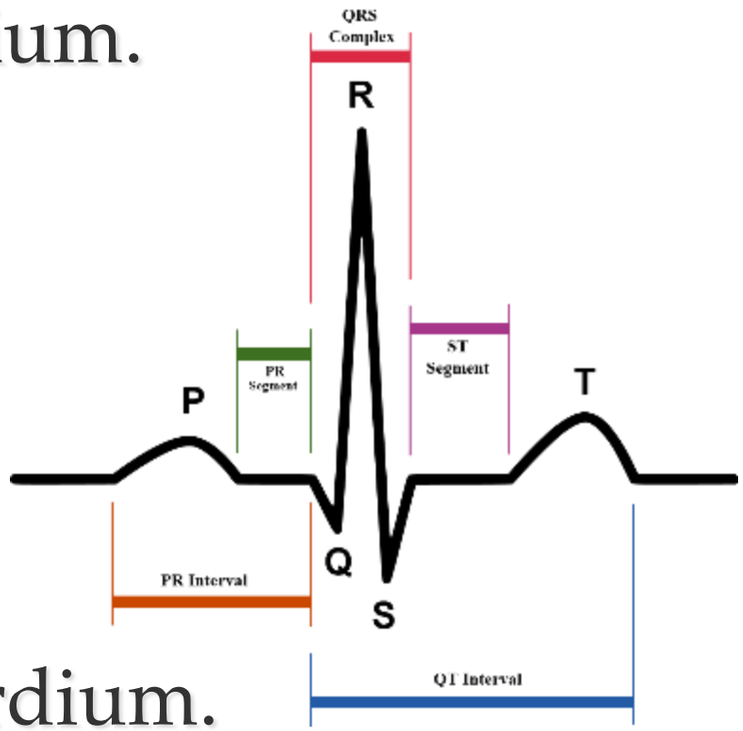

Name:
ID:
Patient ID:
Incident:
Age: 26
Sex:
12-Lead 2
PR 0.138s
QT/QTc
P-QRS-T Axes
HR 62 bpm
14:37:18
QRS 0.112s
0.398s/0.395s
27° 80° 49°
• Normal ECG **Unconfirmed**
• Normal sinus rhythm
I
II
III
aVR
aVL
aVF
V1
V2
V3
V4
V5
V6
x1.0 .05-150Hz 25mm/sec


1 mV (10 mm high) reference pulse
One large 5 mm × 5 mm box represents 0.2 seconds (200 ms) time and 0.5 mV amplitude.
One small 1 mm × 1 mm block represents 40 ms time and 0.1 mV amplitude.
Amplitude
Time


I
II
III
aVR
aVL
aVF
V1
V2
V3
V4
V5
V6
25.0 mm/s
5.0 mm/mV

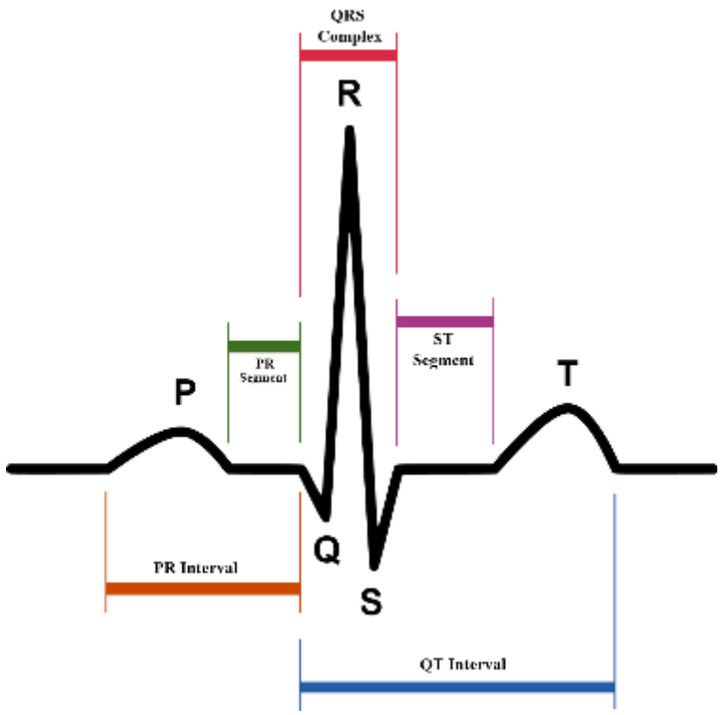
Normal ECG Signal (1/2)

- P waves
  - The depolarization of the atrial myocardium.
- PR interval
  - Between the beginning of the P wave and the beginning of QRS complex.
- QRS complex
  - The depolarization of ventricular myocardium.
  - Before the onset of ventricular systole.
  - R peaks are important for heart rate monitoring



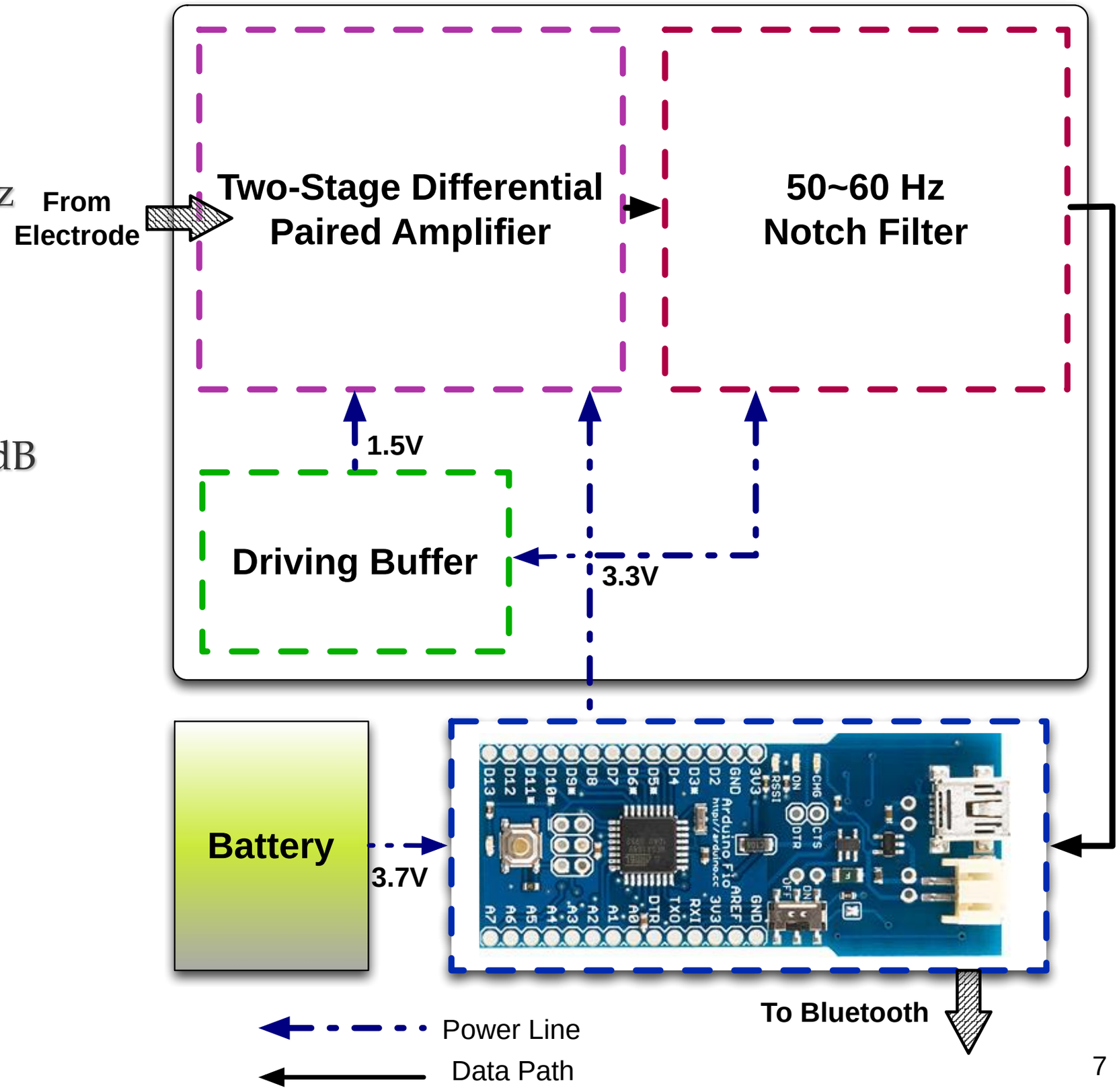
Normal ECG Signal (2/2)

- T waves
  - The repolarization of the ventricular myocardium.
- QT interval
  - Between the beginning of the P wave and the beginning of QRS complex.
- Corrected QT interval
  - $\mathrm{QTc} = \dfrac{\text{time interval from Q onset to T peak}}{\sqrt{\text{Previous RR interval}}}$



Front-End Circuits and Power Supply

- Amplifier
  - 1500X for ECG
  - -3dB frequencies at 1 Hz and 1.1 kHz
- Notch Filter
  - Cut off at 59.9 Hz
  - Depth of the null is -29dB
- Driving Buffer
  - Convert 3.3 V to 1.5 V



Difference Operation Method Algorithm (1/3)

- 60 Hz filtering:

$$x[i] = \frac{1}{M} \sum_{K=i-M/2}^{i+M/2-1} r[k].$$

- Slope calculation:

$$X_d[i] = 2x[i] + x[i-n] - x[i-2n] - 2x[i-3n].$$

- Squaring and flattening:

$$\hat{X}_d[i] = X_d^2[i], \qquad \hat{X}_{df}[i] = \frac{1}{N} \sum_{k=i-N/2}^{i+N/2-1} \hat{X}_d[k].$$

- Adaptive threshold calculation:

$$TH = \frac{1}{S/2} \sum_{n-S/4}^{n+S/4} \hat{X}_{df}[i].$$

Difference Operation Method Algorithm (2/3)

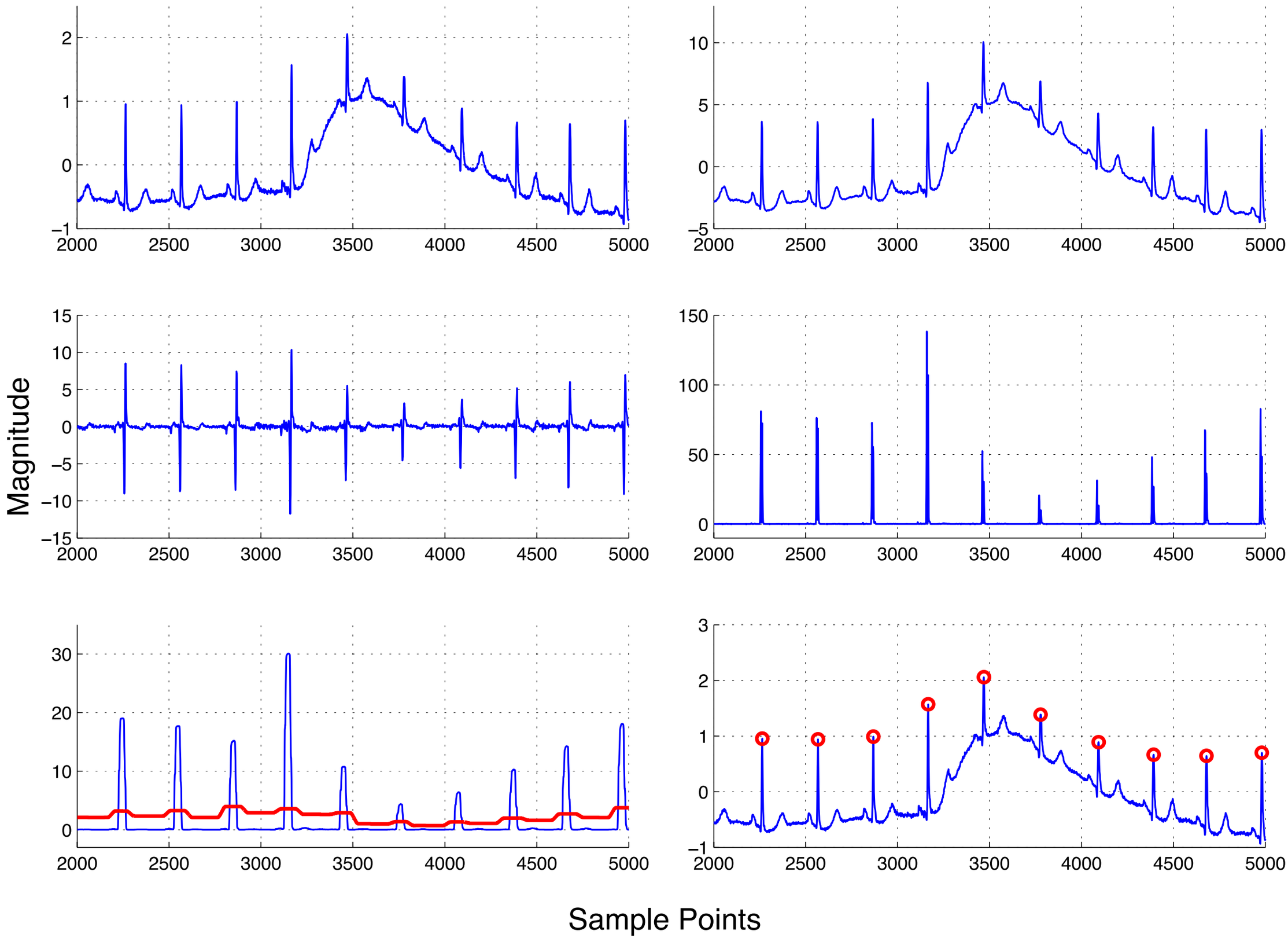
- Hard threshold:

$$\hat{X}_{dfT}[i] = \hat{X}_{df}[i] - TH, \quad \begin{cases} \hat{X}_{dfT}[i], & \hat{X}_{df}[i] - TH > 0 \\ 0 & \hat{X}_{df}[i] - TH < 0 \end{cases}$$

- Slope local maximum detection
  - Find the time index *i* of the local maximum of the slope.

- ECG local maximum detection:
  - Use the sample index *i* to find the local maximum of original ECG signal by applying a short searching range.
  - Searching region is set to be 0.1 second since normal QRS complex (5-40Hz) is about 80~100 ms duration.

Difference Operation Method Algorithm (3/3)



Beats (Peaks) Detection Algorithm on Mobile Hub (1/2)

- Power Line Noise Filter

$$data[i] = \frac{1}{M} \sum_{k=i-M/2}^{i+M/2-1} r[k],$$

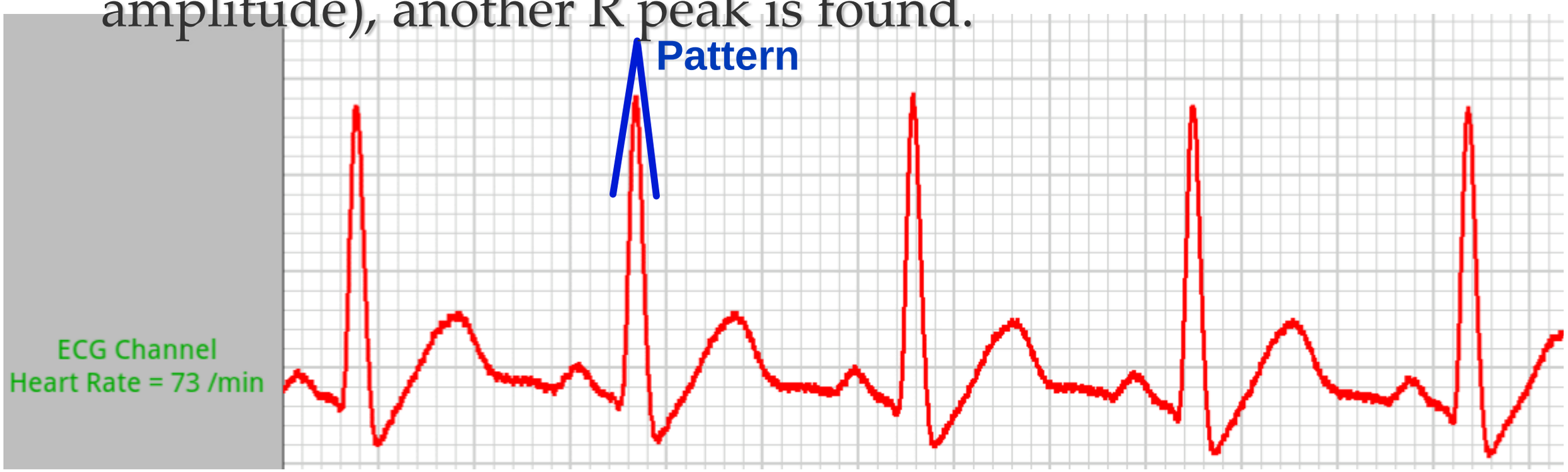
$$H[f] = \frac{\sin(\pi f M)}{M \sin(\pi f)}\ ; \quad f = f_{cut}/f_s,$$

- Baseline Noise Filter

$$\text{baseline}[i] = \frac{1}{\text{N}} \sum_{j=0}^{N} (\text{Q}[i-j] + \text{S}[i-j]),$$

Beats (Peaks) Detection Algorithm on Mobile Hub (2/2)

- R Peak Pattern Generation
  - Generate **adaptive** R peak pattern at the beginning of sensing
  - The pattern looks like an up arrow
- Sense Later ECG Waveform by the Pattern
  - If there is a wave shape match (similar slope and amplitude), another R peak is found.



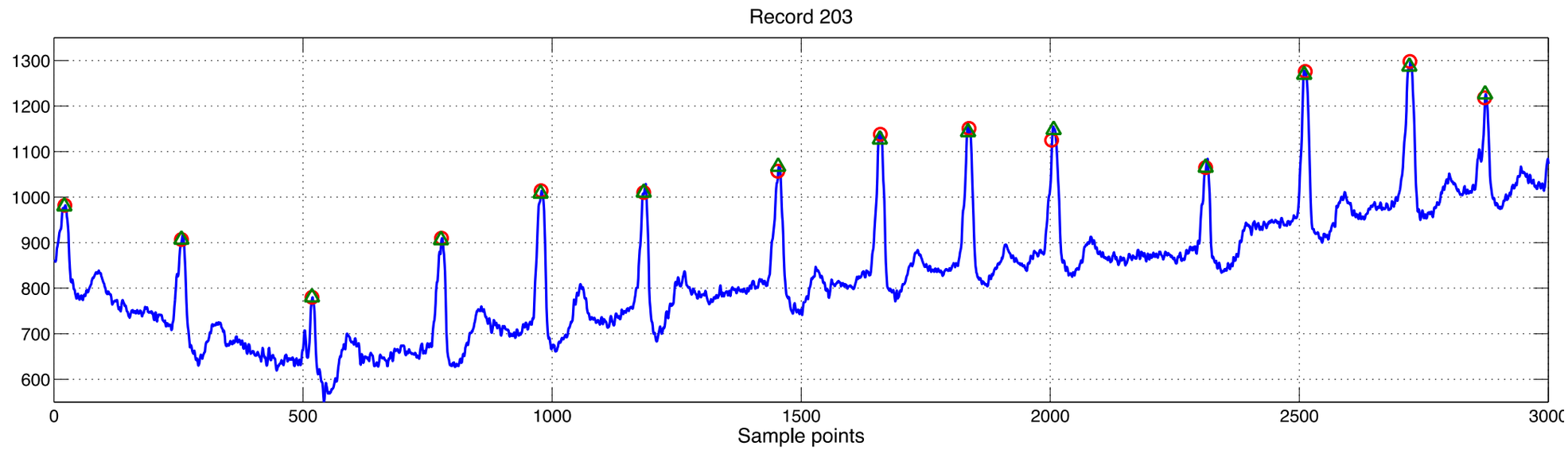
ECG Noise Reduction [2-5]

- Noise types:
  - Baseline wander (BW) (below 1Hz)
  - 50 or 60 Hz power-line interference (PLI)
  - Electromyogram (EMG)
  - Motion artifact (MA)

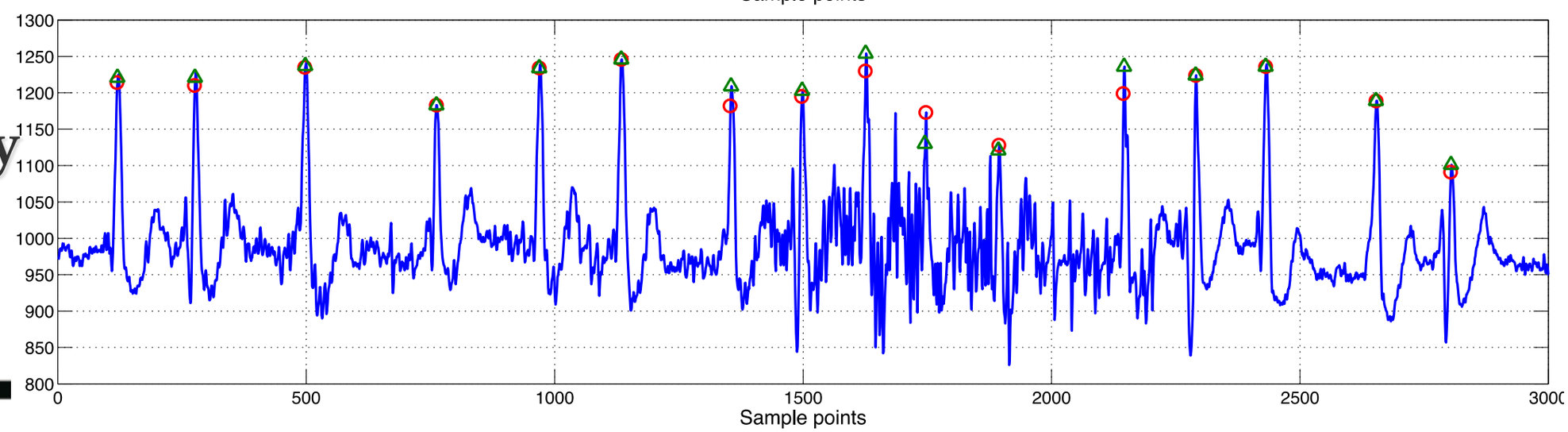
Method	Noise Type
Adaptive Filter	BW, PLI, MA
Wavelet Transform	BW, EMG, MA
Empirical Mode Decomposition	BW, EMG, MA
Independent Component Analysis	MA
Moving Average	BW, MA

ECG Signal and Interferences [6]

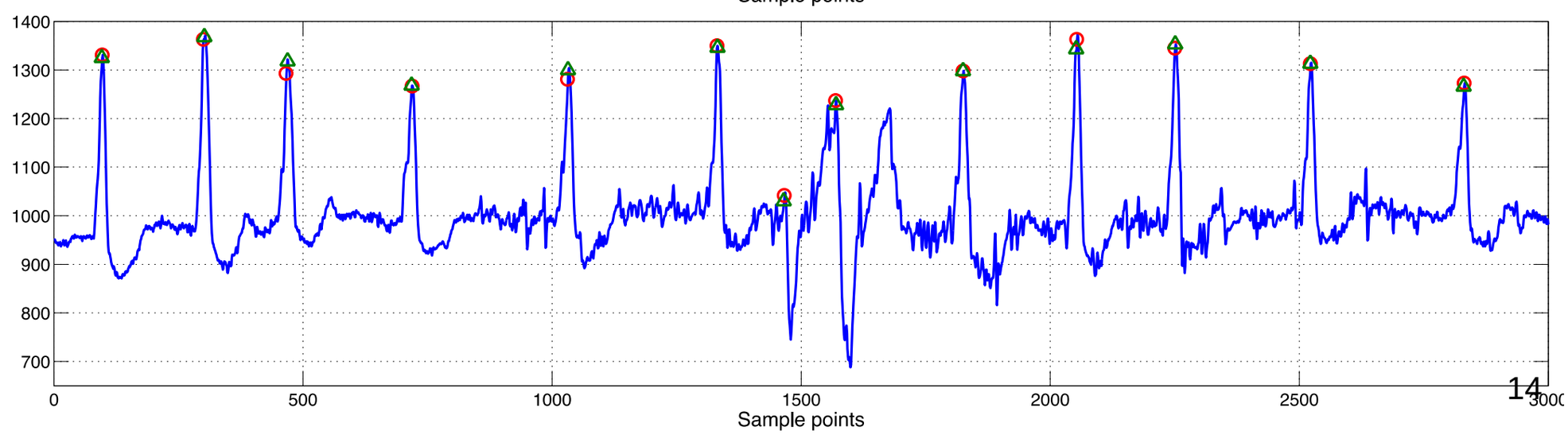
Baseline Noise



Electromyography Noise



Motion Artifact



Analysis

- Parameters
  - FN: Real R peaks missed
  - FP: Existed R peaks missed
  - Error rate: $\mathrm{ER} = \frac{\mathrm{FN}+\mathrm{FP}}{\text{Total beats}}$