ESE 3400: Medical Devices Lab

Lec 8: September 28, 2022

Electrocardiogram and Heart Rate

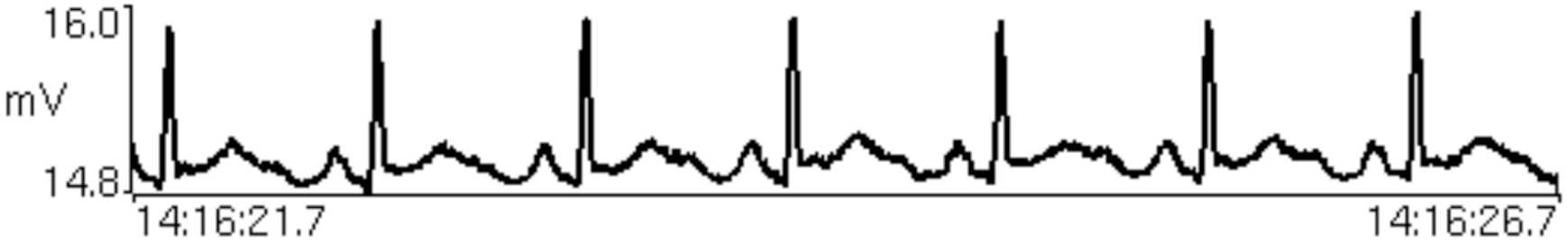
(based on slides from Dr. Gari Clifford, Oxford)

Lecture Outline

- ECG signal
  - PQRST
  - Heart Rate
- Electrode placement
  - Einthoven's Triangle
  - 10-Electrode (12-Lead) ECG
- Diagnostic uses of ECG
- Heart rate monitors

The Electrocardiogram

- If two surface electrodes are attached to the upper body (thorax), the following electrical signal will be observed:



- This is the ECG

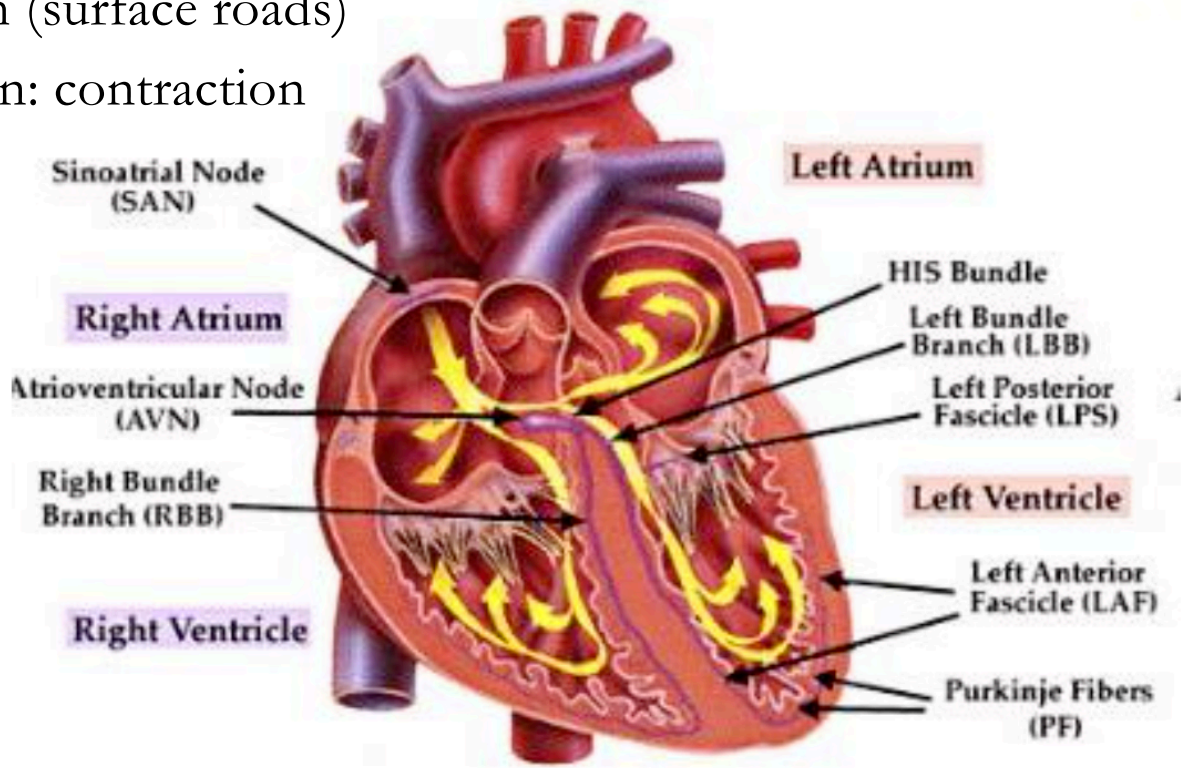
- Usually use more than just two electrodes…

The Origin of the ECG

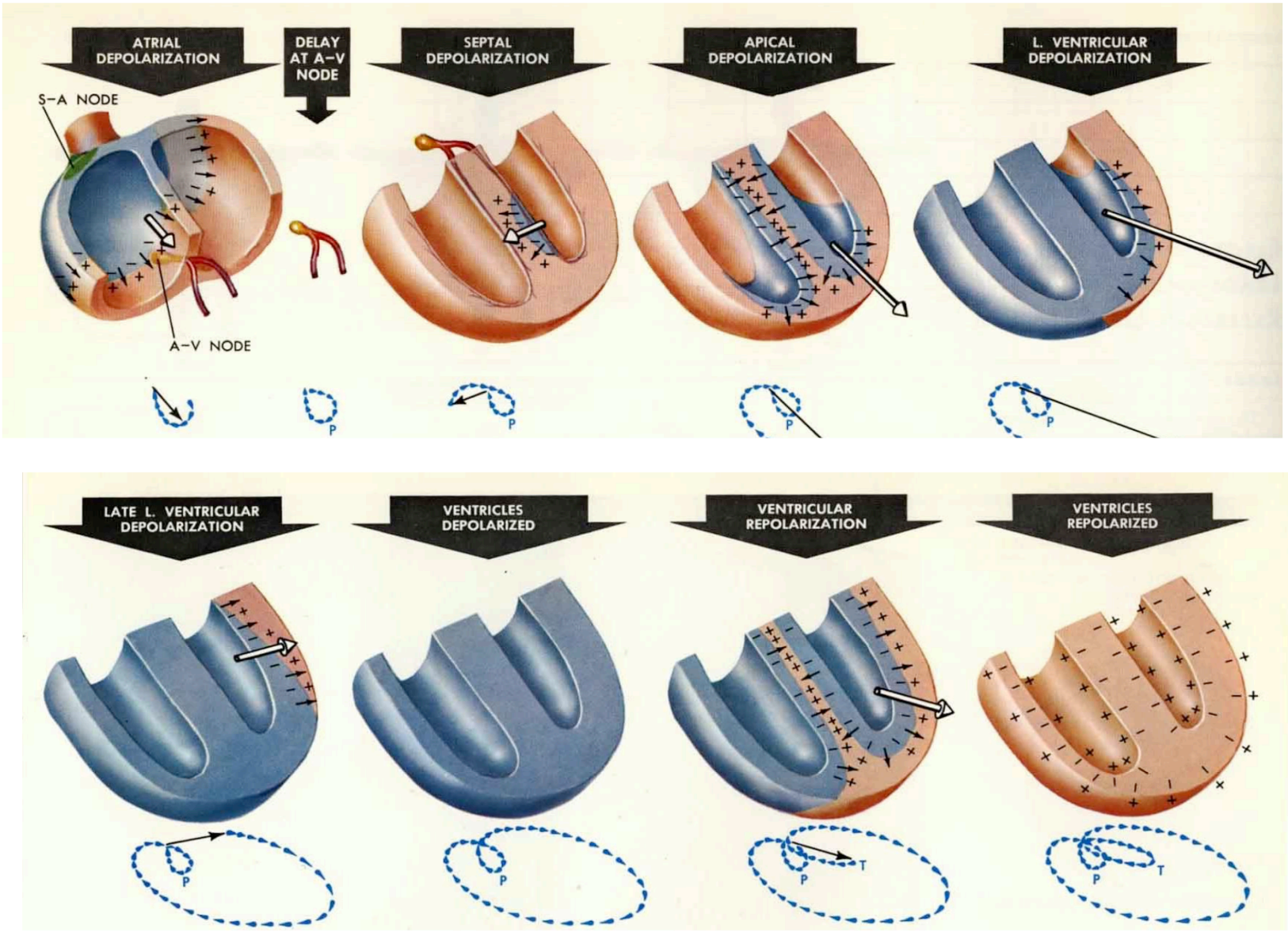
- Atrial and ventricular contractions are the result of carefully timed depolarizations of the cardiac muscle cells
- The timing of the heart cycle depends on:
  - Stimulus from the pacemaker cells
  - Propagation between muscle cells
  - Non-excitable cells
  - Specialized conducting cells (Atrio-Ventricular Node)

Important Specific Structures

- Sino-atrial node = pacemaker (usually)
- Atria
- After electrical excitation: contraction
- Atrioventricular node (a tactical pause)
- Ventricular conducting fibers (freeways)
- Ventricular myocardium (surface roads)
- After electrical excitation: contraction

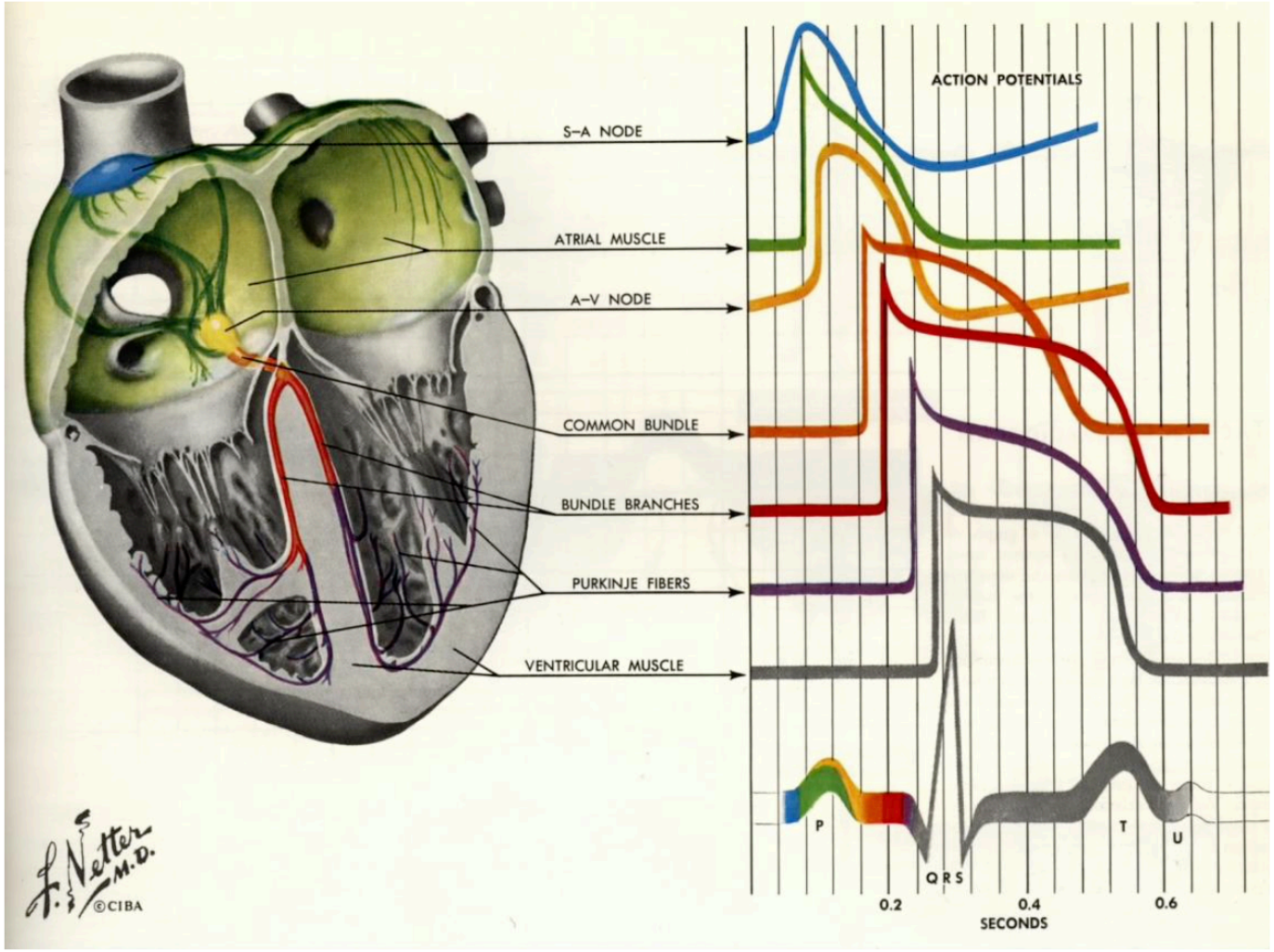


Excitation of the Heart

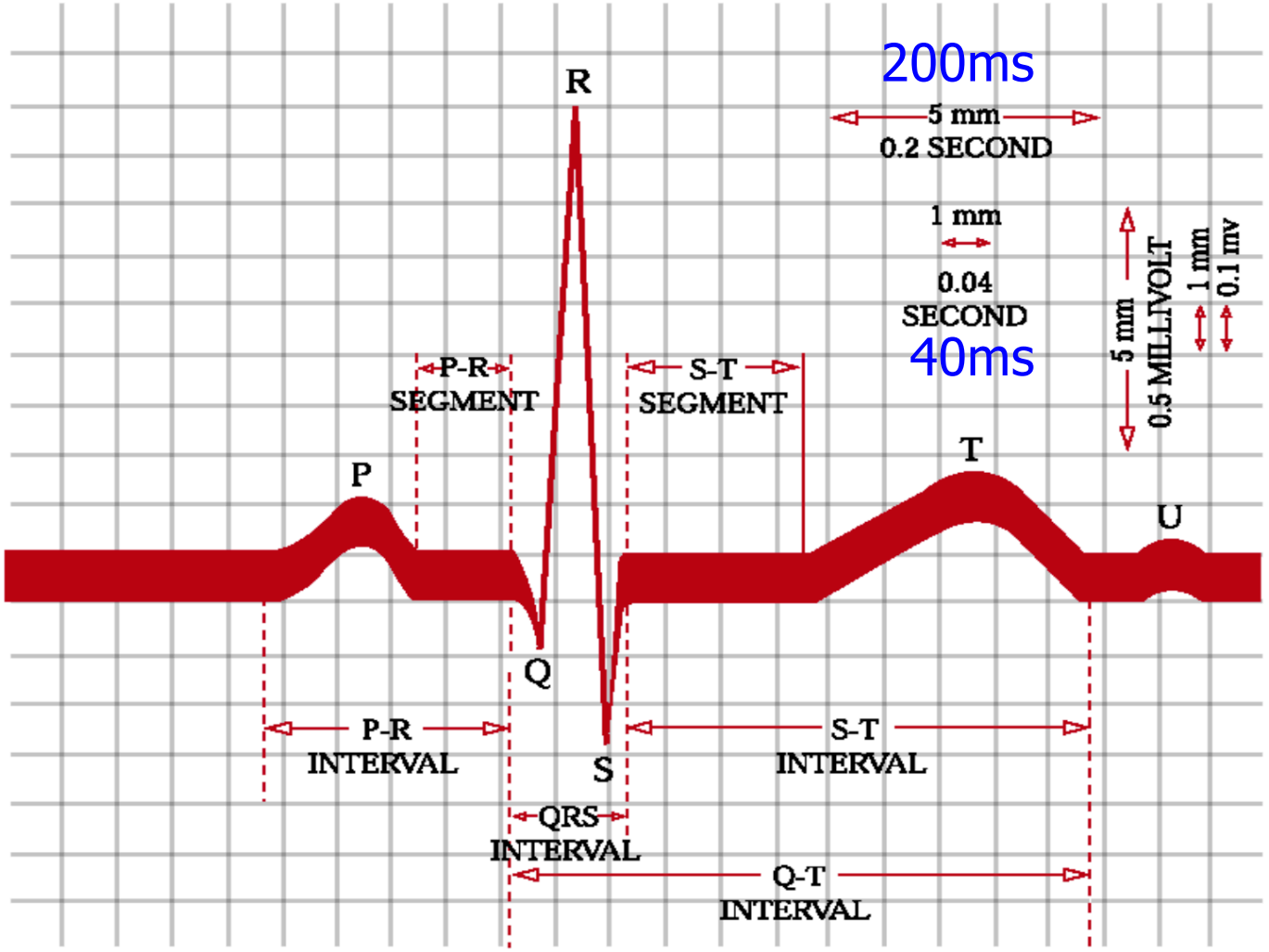


Cardiac Electrical Activity

- Putting it all together:



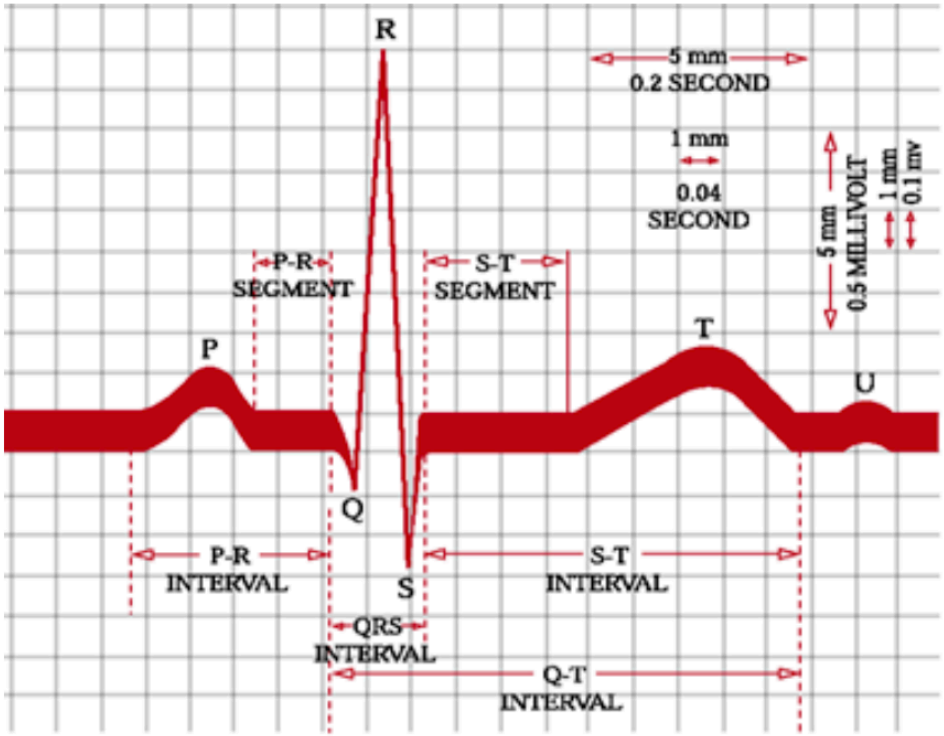
Typical ECG Signal



Recording Conventions, Waveform Nomenclature, and Normal Values for the Electrocardiogram.

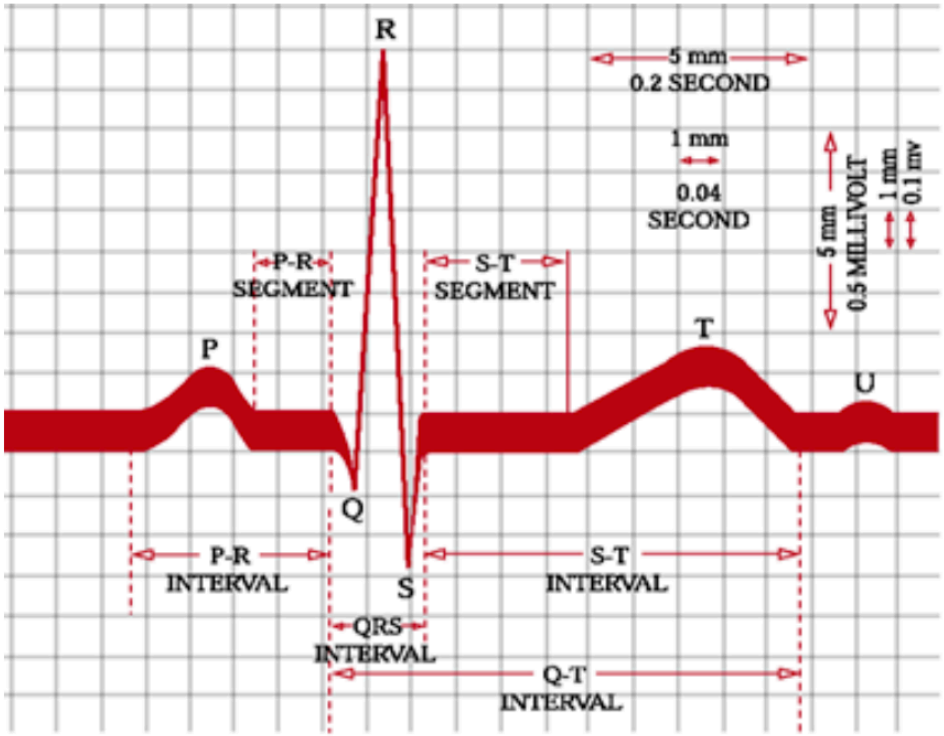
Components of ECG Signal

- P-wave: a small low-voltage deflection caused by the depolarization of the atria prior to atrial contraction
- QRS complex: the largest-amplitude portion of the ECG, caused by currents generated when the ventricles depolarize prior to their contraction



Components of ECG Signal

- T-wave: ventricular repolarization
- P-Q interval: time interval between the beginning of the P wave and the beginning of the QRS complex
- Q-T interval: characterizes ventricular repolarization



Heart Rate

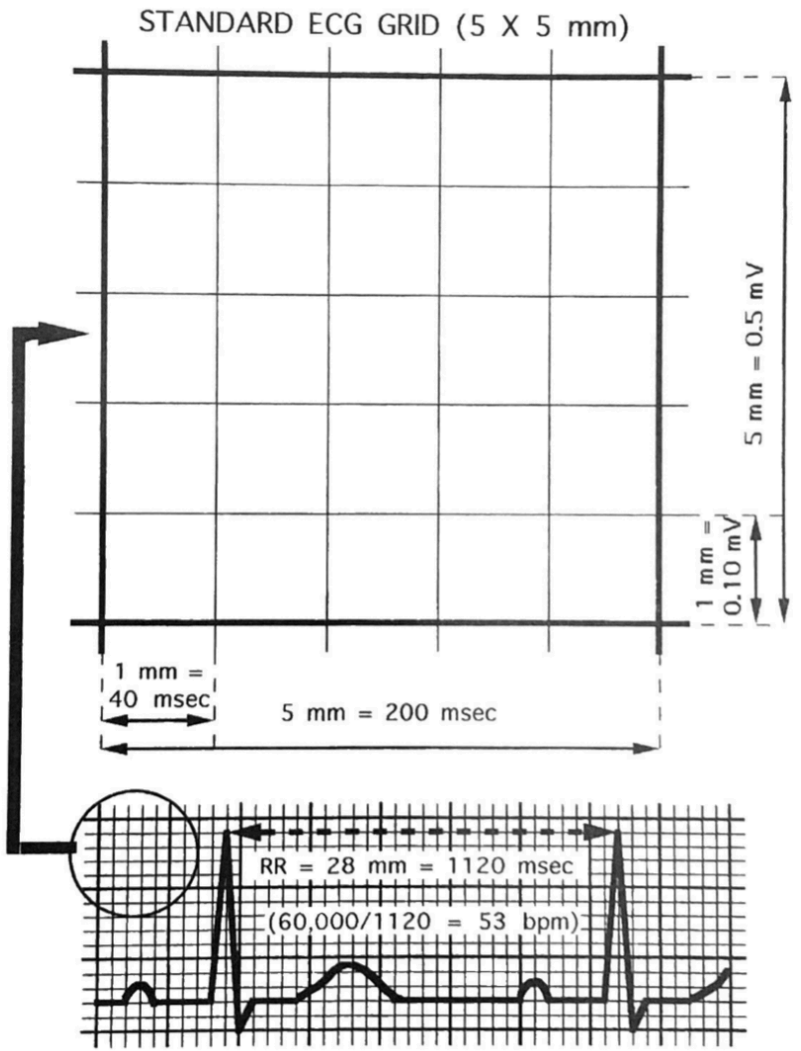
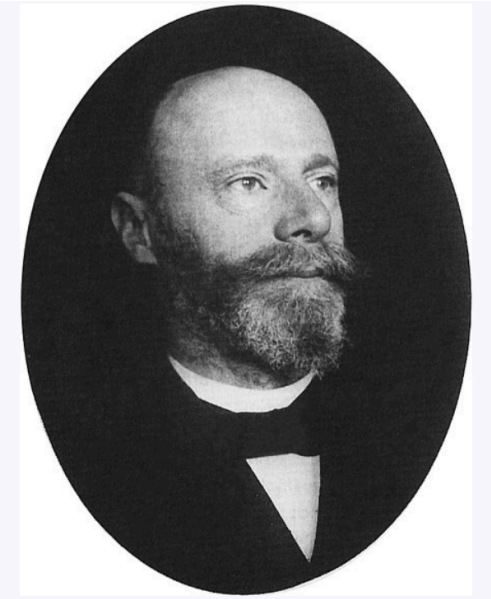


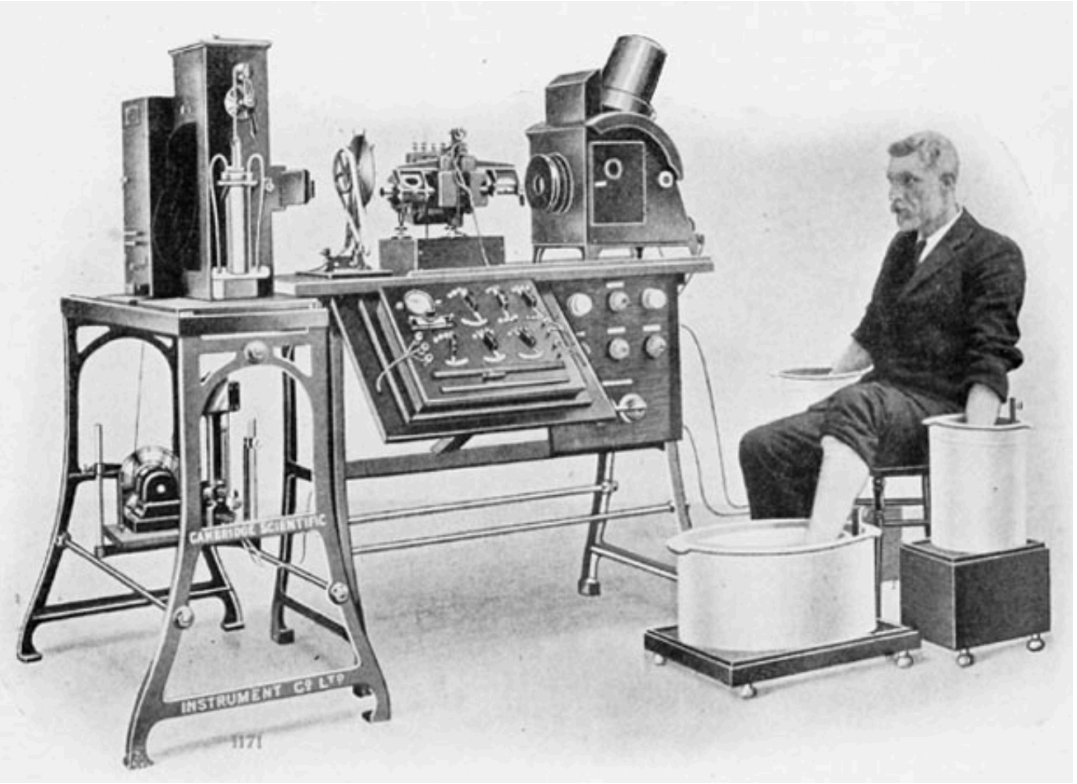
FIGURE 2.8

Heart rate determination.

ECG Measurement

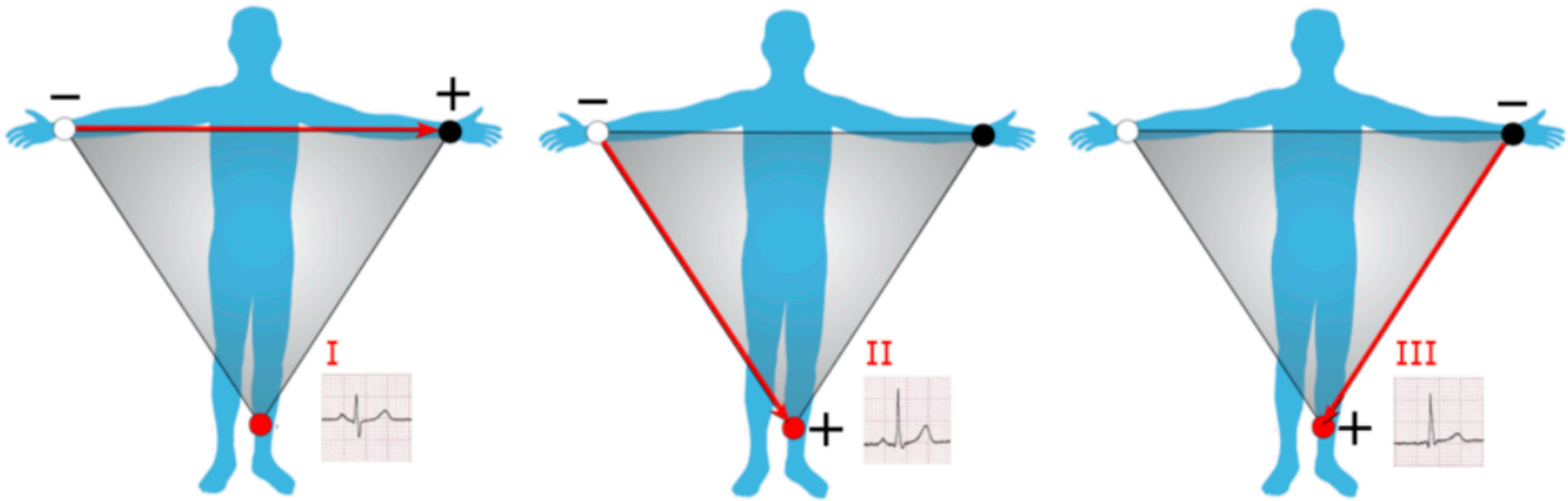
- Willem Einthoven
  - Invented string galvanometer
  - His assignment of the letters P, Q, R, S and T to the various deflections are still used





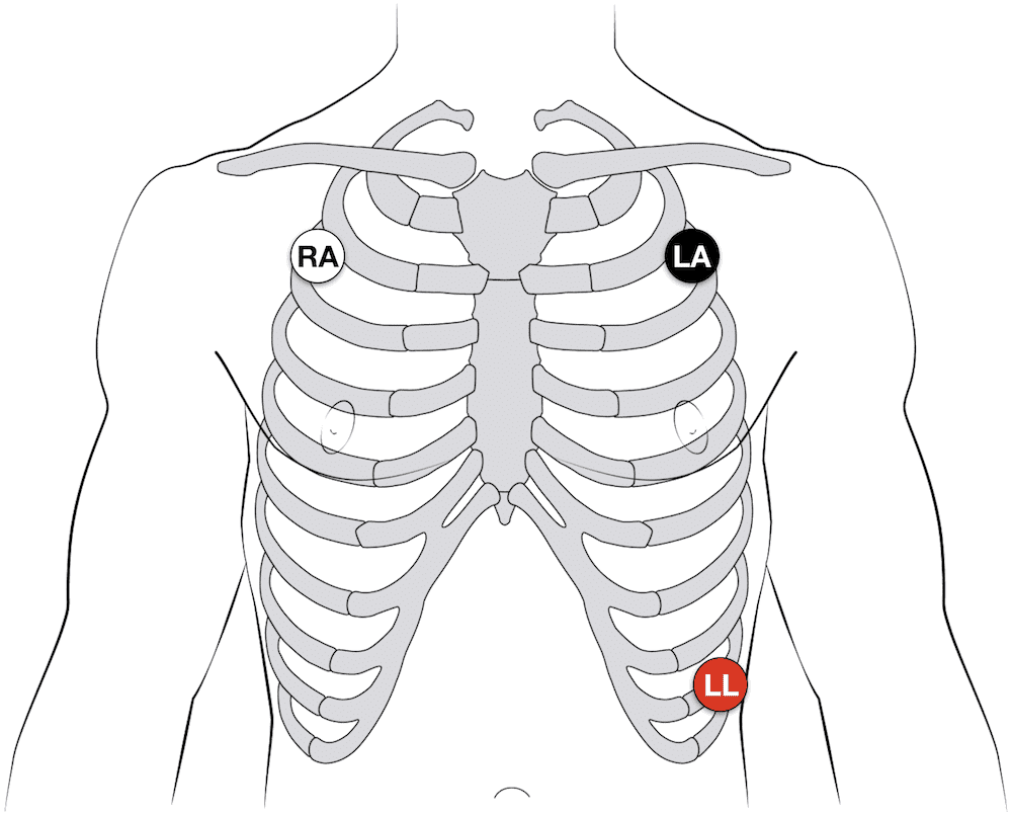
Einthoven's Triangle

- Lead I = LA - RA
- Lead II = LL - RA
- Lead III = LL - LA



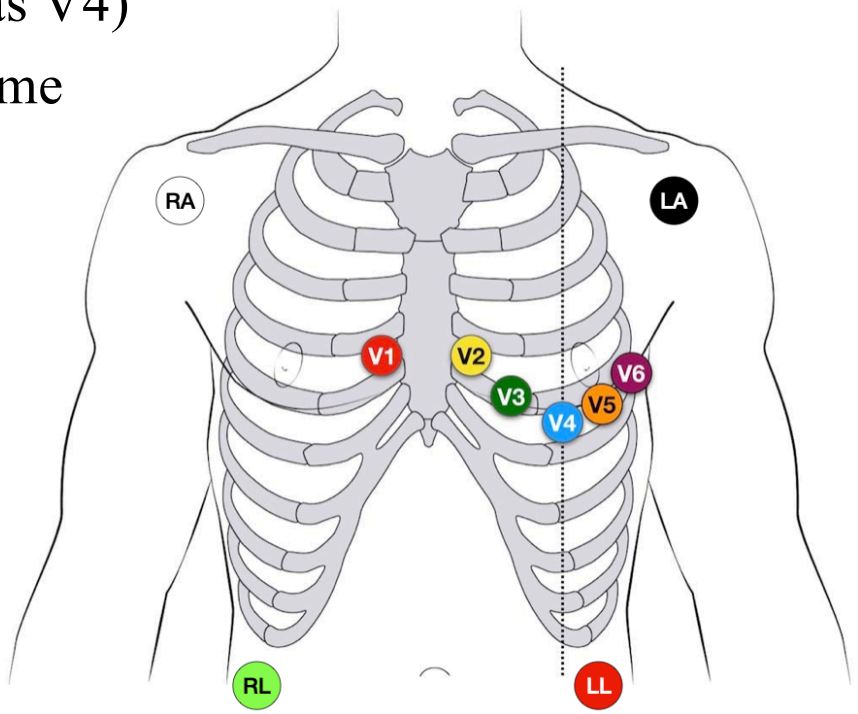
3-Electrode System

- Uses **3** electrodes (RA, LA and LL)
- Monitor displays the bipolar leads (I, II and III)
- To get best results – Place electrodes on the chest wall equidistant from the heart (rather than the specific limbs)



10-Electrode System (12-Lead ECG)

- V1: at the 4th intercostal space (ICS), on the right sternal border
- V2: 4th ICS, along the left sternal border
- V4: 5th ICS, at the mid-clavicular line
- V6: 5th ICS, mid-axillary line (same level as V4)
- V5: 5th ICS, at the anterior axillary line (same level as V4)
- V3: midway between V2 and V4



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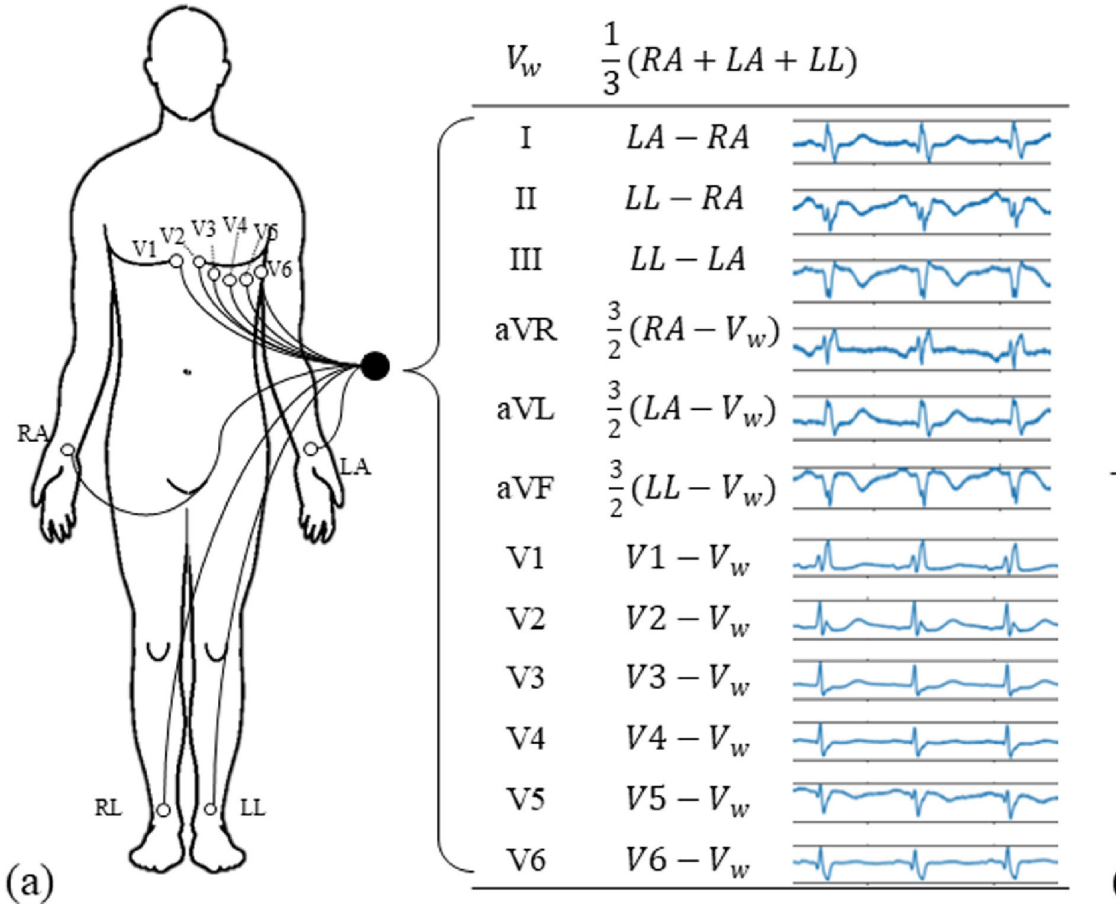

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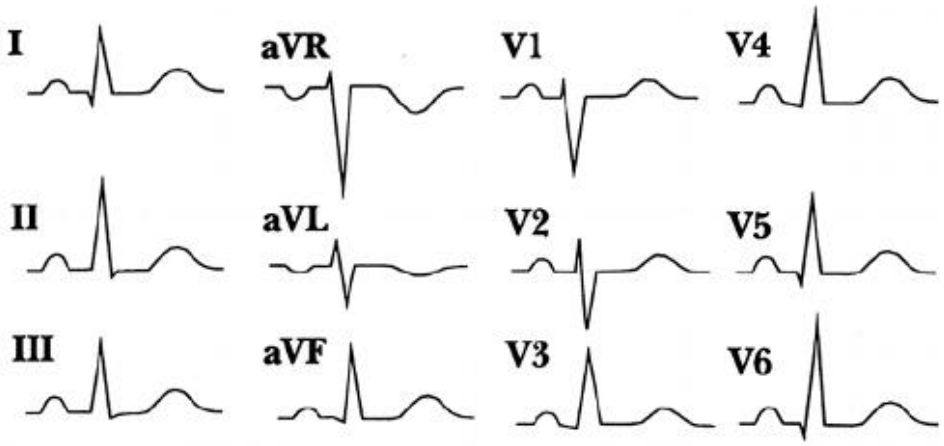
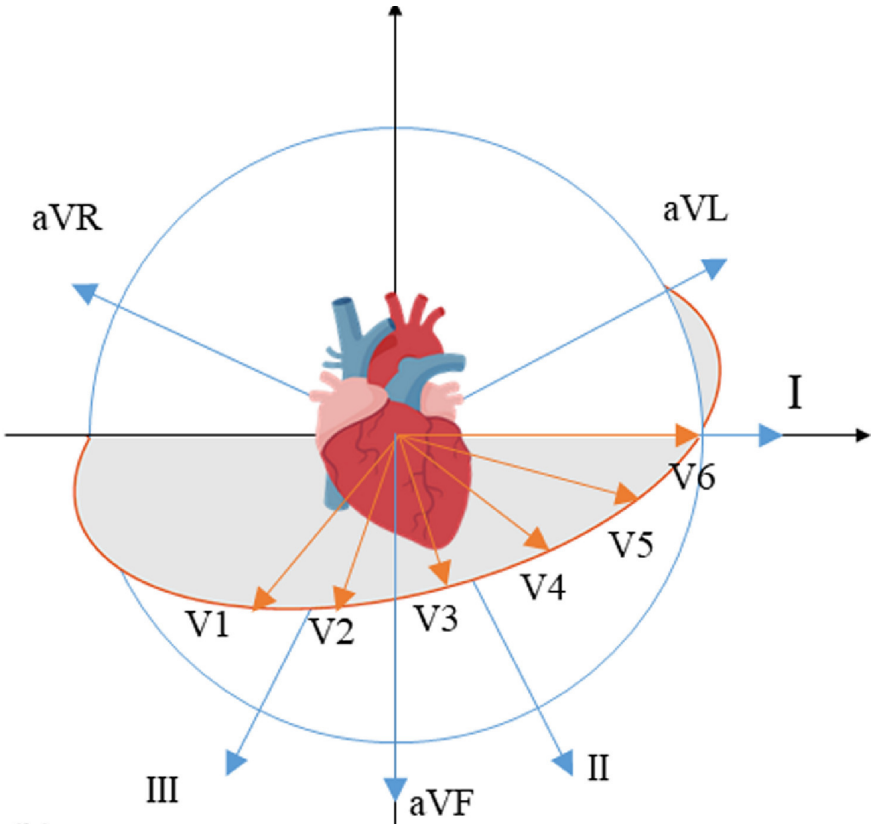




Diagnostic Uses of ECG

- Fetal monitoring (both before birth & during)
- Patient monitoring in Ambulance, Intensive Care Unit or Coronary Care Unit
  - S-T segment elevation to diagnose heart attacks
  - Evidence of cardiac muscle damage (infarct)
- Detection of precursors to heart attacks:
  - Abnormal heart beats (e.g. many ectopic beats, TWA)
  - Abnormal heart rhythms

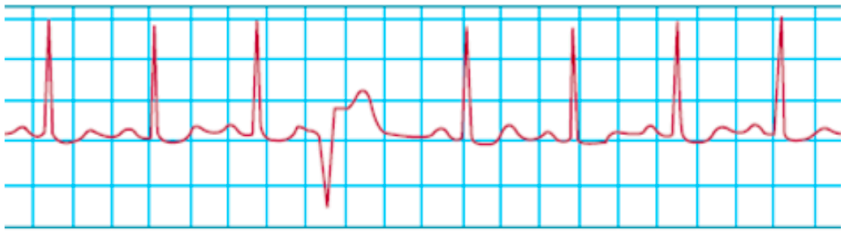
Use of ECG in CCU

- The ECG is highly informative in the diagnosis of a heart attack (Myocardial Infarct)
  - Insufficient blood supply to the cardiac cells due to a blockage in the coronary arteries (ischaemic heart condition) causes S-T segment elevation

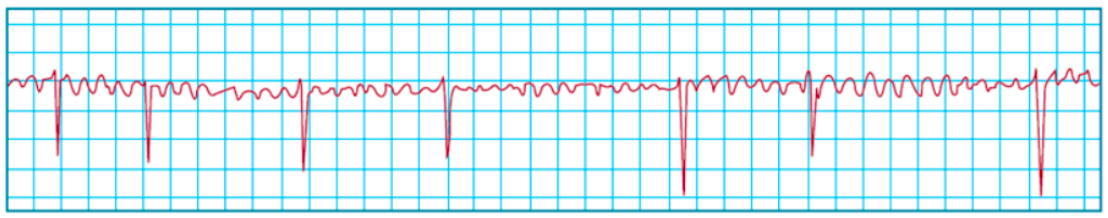
  - After the heart attack, cardiac muscle damage (infarct) generally leads to a loss of amplitude in the ECG

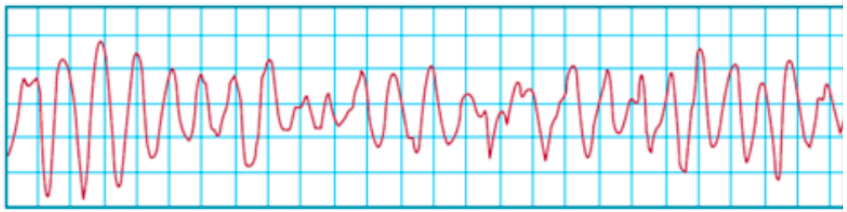
ECG Abnormalities

- Analysis of the ECG can provide early warning of potential problems
- Ectopic beats originate somewhere other than the Sino-Atrial (SA) node and often have different shapes (morphologies)



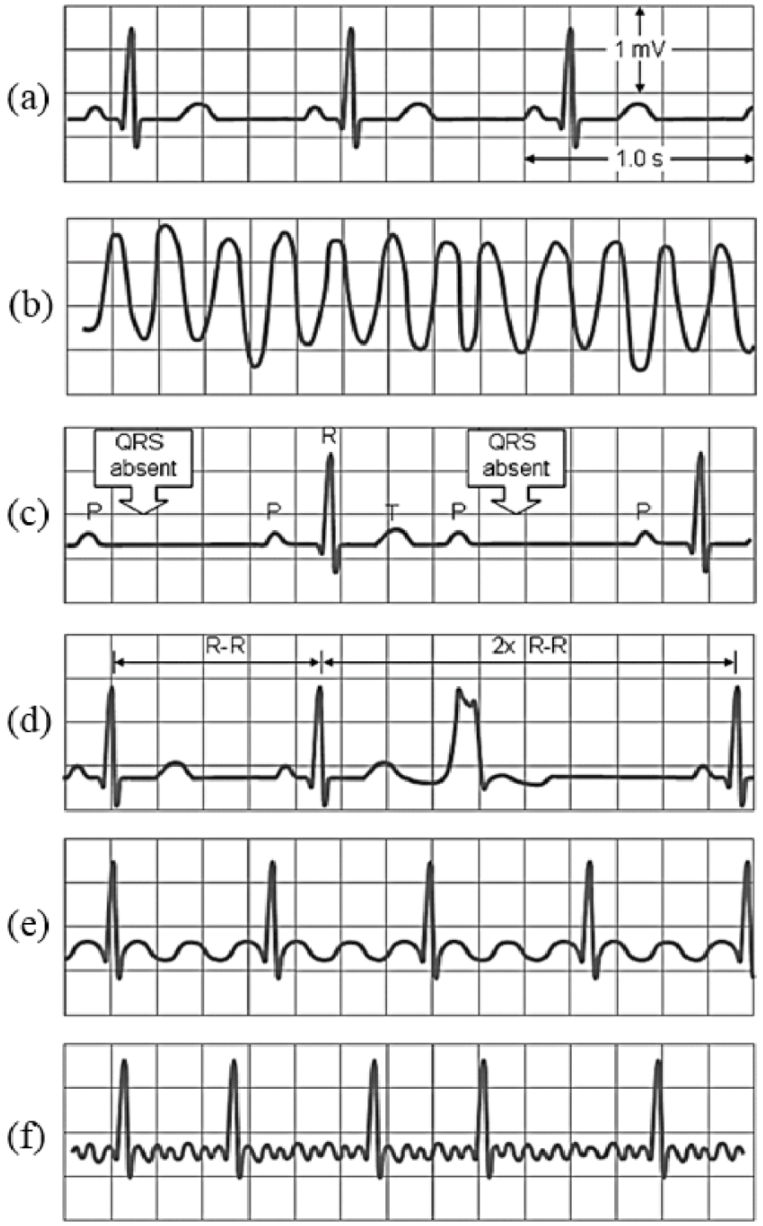
- Abnormal heart rates (arrhythmias) can be treated



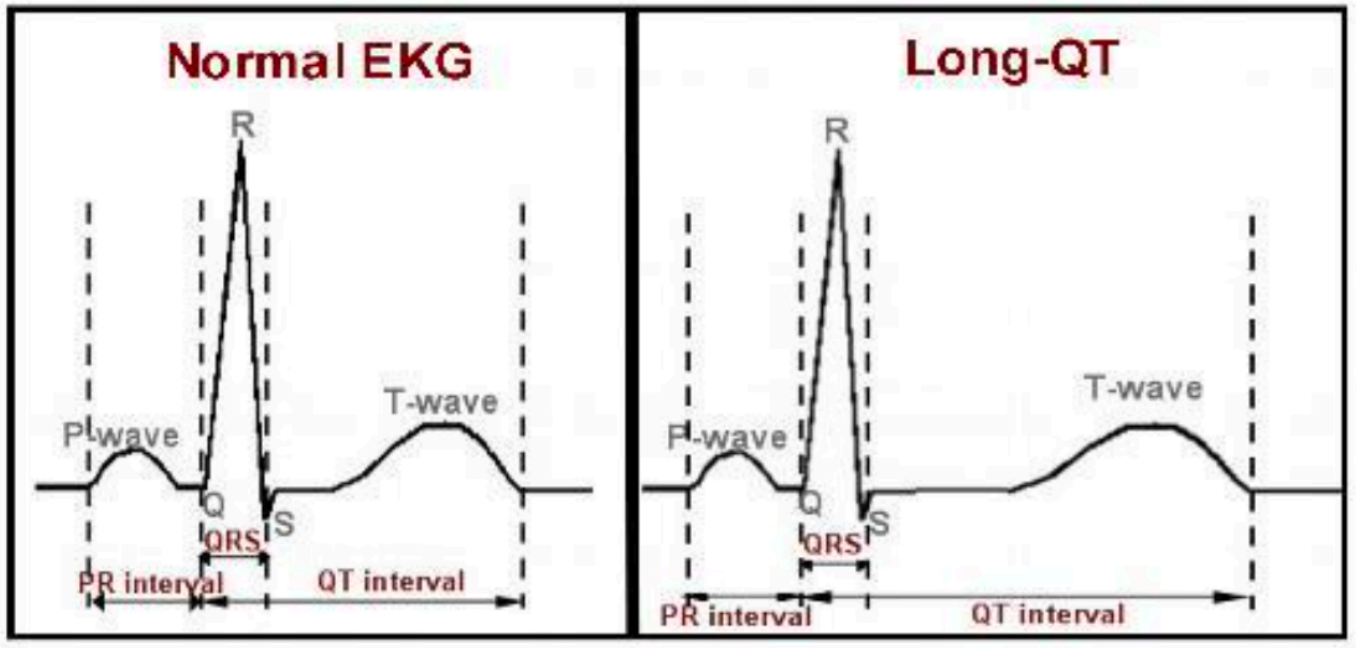


Abnormal ECGs

- (a) Normal Sinus Rhythm
- (b) Ventricular Fibrillation
- (c) Atrioventricular Block
- (d) Premature Ventricular Contraction
- (e) Atrial Flutter
- (f) Atrial Fibrillation



Other Intervals in ECG Analysis



- The most important interval in the ECG is the QT interval
- A longer than normal QT interval is a good indicator of long QT syndrome (LQTS)

QT Interval Measurement

- LQTS is a potentially fatal condition that renders sufferers vulnerable to an arrhythmia known as torsade de pointes
- When this rhythm occurs, the heart is unable to beat effectively and the blood flow to the brain falls dramatically
- The result is a sudden loss of consciousness and possible cardiac death

Detecting ECG Abnormalities

- Two methods are in common use:
  - Ambulatory monitoring
  - Exercise stress ECGs

Ambulatory ECG Monitoring

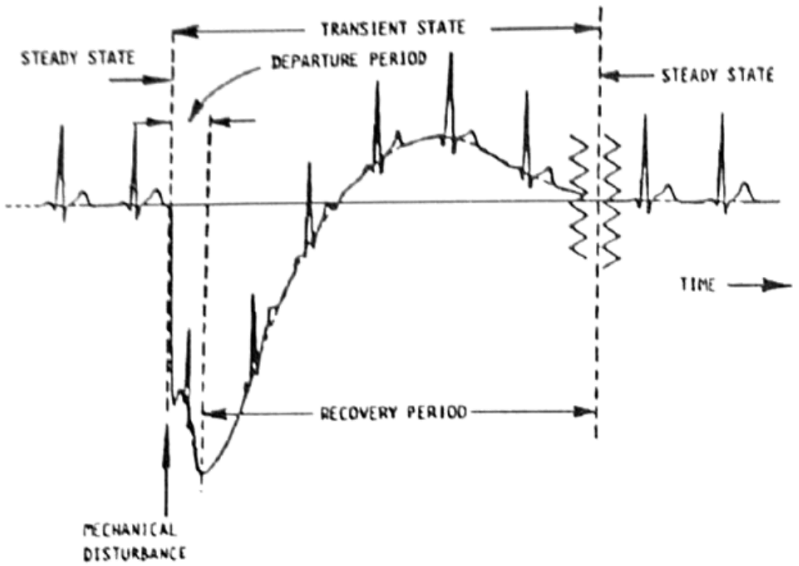
- ECG monitored for 24 hours.
- Results printed out:
  - 24-hour summary detailing the heart rate and S-T segment changes over the period of the test
  - Detailed information on ECG recorded at the time of a significant event (e.g. arrhythmia)

Analysis of ECG waveform

- Diagnostic information can be obtained by analysis of the amplitude and relative timing of the various segments
- The simplest interval to measure is the R-R interval (from which the heart rate is derived)
- Two types of heart rate meters:
  - Averaging heart rate meter
  - Beat-to-beat heart rate meter

QRS detection

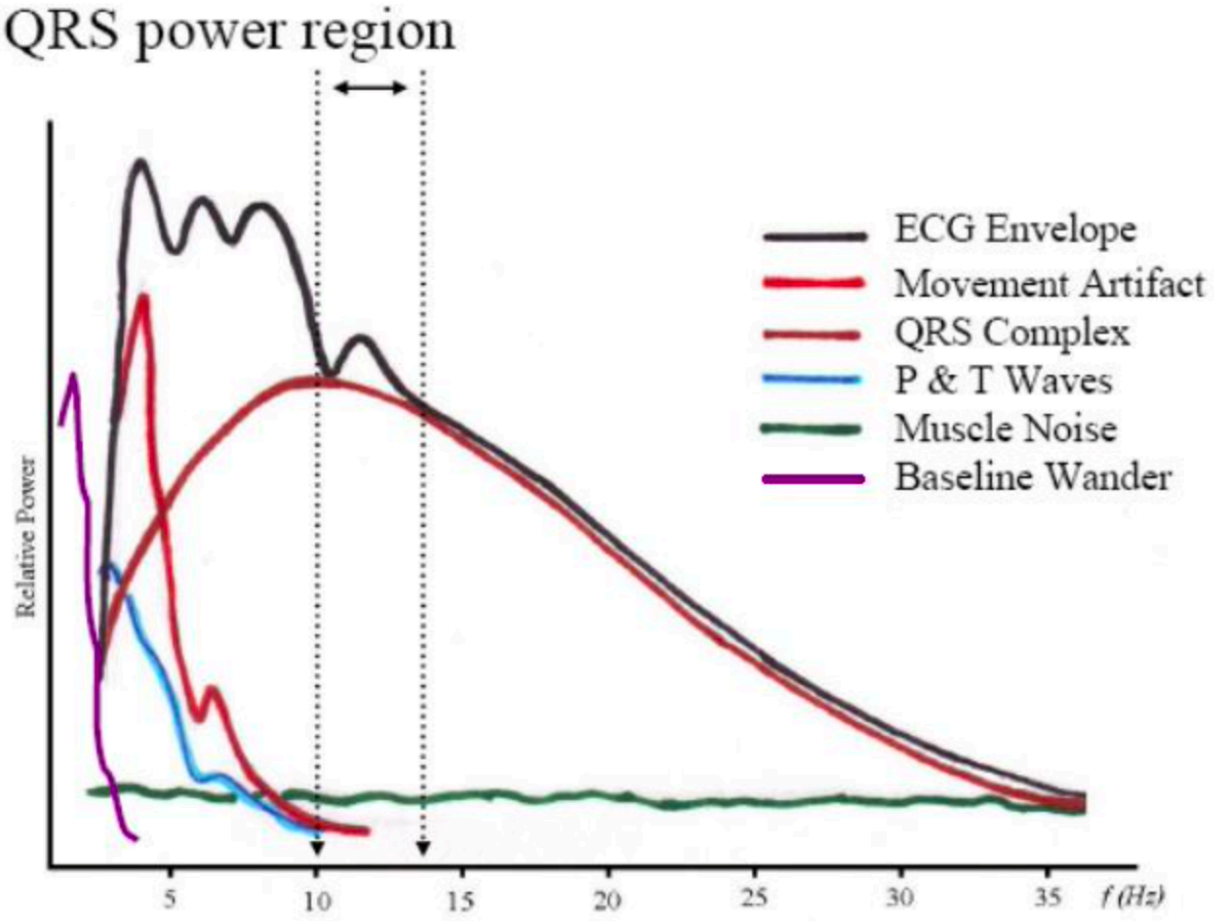
- There are 4 main problems in detecting the QRS complex in ECG traces:
  - Artifacts due to electrode motion
  - Baseline wander (mostly caused by breathing and torso movements)
  - Muscle artifact (broadband)
  - T-waves with high-amplitude content



QRS Detection

- The solution to these problems is to use a band-pass filter to remove:
  - Low-frequency changes such as baseline wander
  - High-frequency changes e.g. movement/muscle artifact
- Most of the frequencies in the QRS complex are around 5-20 Hz

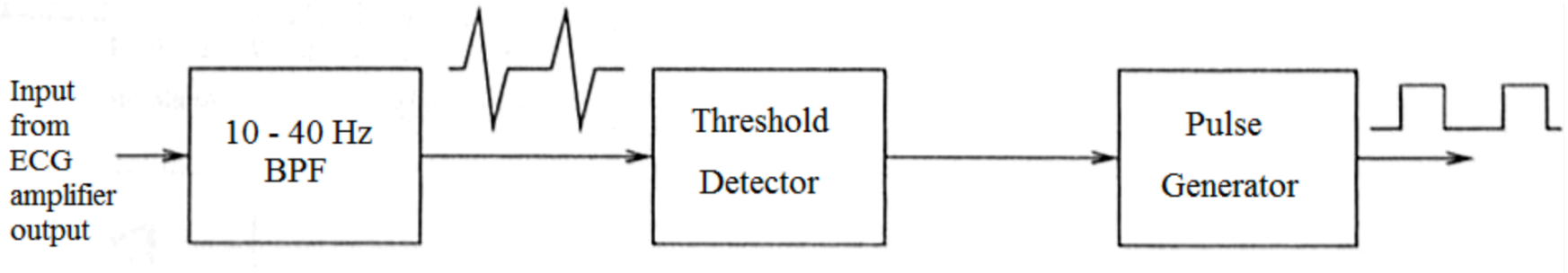
ECG Spectral Properties



- A pass-band of 10 – 40 Hz is therefore appropriate

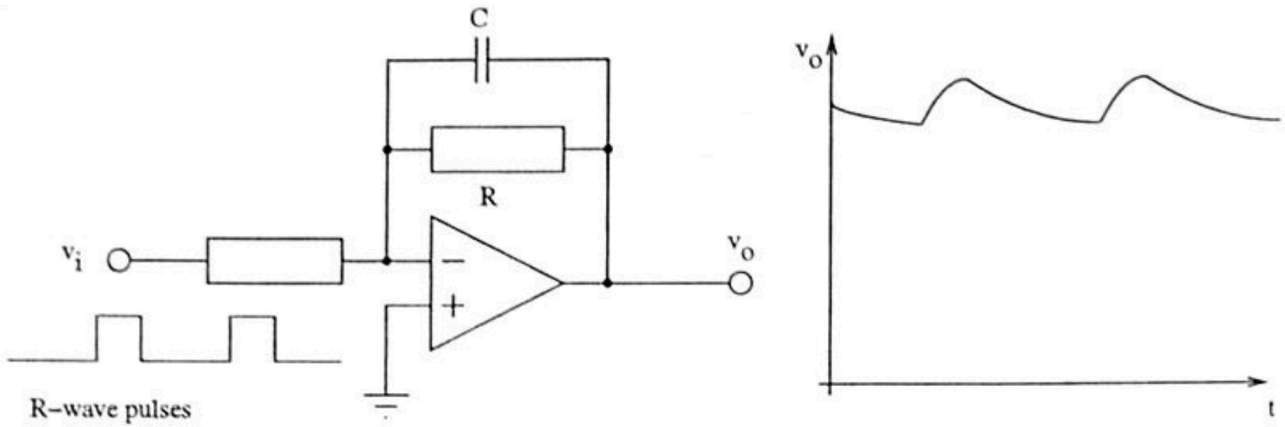
QRS Detection

- Once the "non-QRS" sections of the ECG have been attenuated, the QRS complex can be detected with a threshold detector

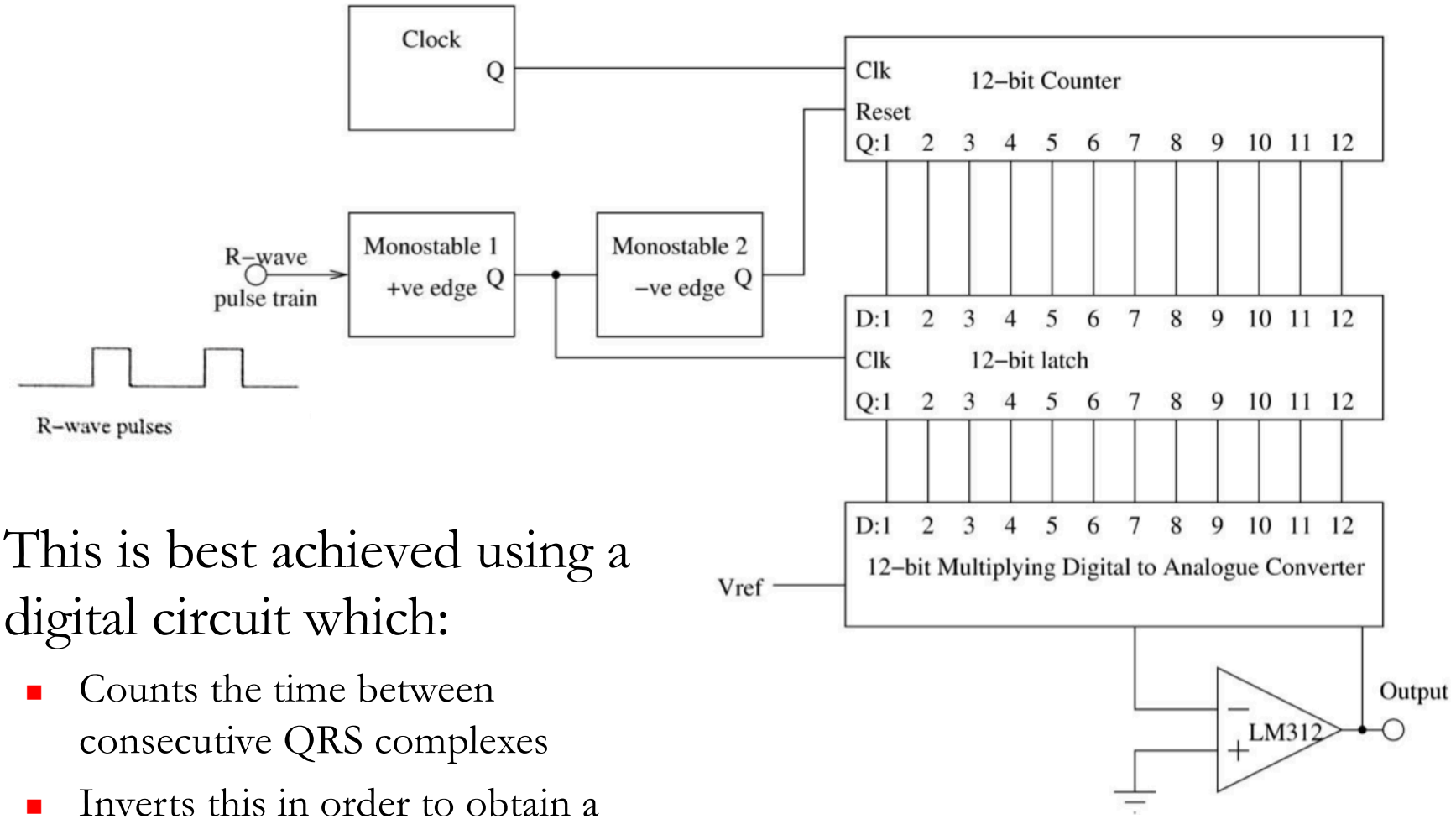


Averaging Heart Rate Meter

- The "average power" of the pulse train from the pulse generator circuit will be indicative of the heart rate
- This can be determined using a "leaky integrator" (a form of low-pass filter).
- The time-constant of the R-C circuit should be several beats long to minimize output ripple.

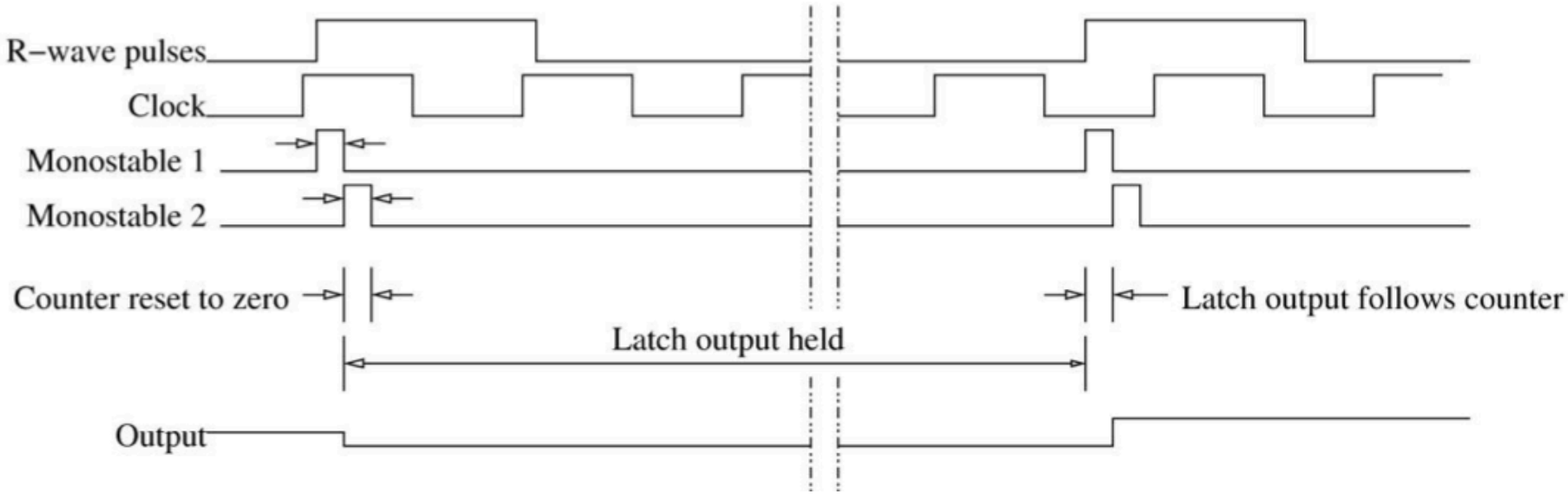


Beat-to-Beat Heart Rate Monitor



- This is best achieved using a digital circuit which:
  - Counts the time between consecutive QRS complexes
  - Inverts this in order to obtain a heart rate (rather than interval)

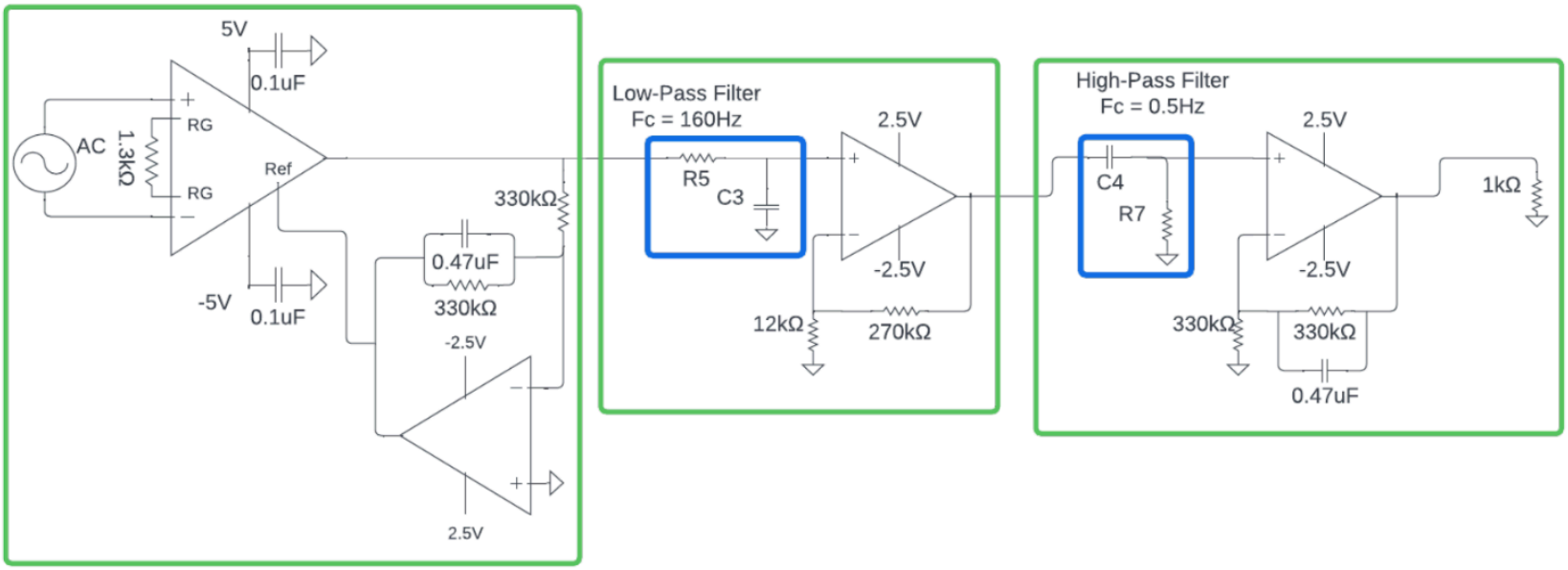
Beat-to-Beat Heart Rate Monitor



Big Ideas

- ECG Signal used to diagnose heart conditions and potentially predict heart failure
  - Electrode placement important in monitoring
- Two kinds of heart rate monitors
  - Averaging and beat-to-beat
    - Use filters and circuitry to detect heart rate

Lab 4 - Breadboarding



Admin

- Finish Lab 3 and 4 and submit deliverables in Canvas by next lab day at midnight
  - Need to start PCB next lab period!
- Moved Quiz 1 to Wednesday after Fall Break instead of Monday
  - See calendar for update