Use of ECG for Diagnostic Purposes

As has already been mentioned, diagnostic information can be obtained from the ECG waveform, by analysis of the amplitude and relative timing of the various segments. 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 on the ECG.

Abnormal heart rates (arrhythmias) can be observed and treated; for examples slow rhythms (bradycardia) can be treated with stimulants or a pacemaker, whilst in the case of fast rhythms (tachycardia) depressants can be prescribed. Ectopic beats are beats which originate from a region of the heart other than the sino-atrial node (pacemaker cells). An ectopic beat in the ventricle causes an extra R-wave, indicative of a premature ventricular contraction (PVC).

These abnormal conditions are usually identified by one of two means:

- **Ambulatory monitoring** for up to 24 hours of patients who have been identified as being at risk of heart attacks. Data compression techniques (e.g. beat-to-beat interval histograms) are often used although advances in memory technology have considerably reduced the need for these.

- **Exercise stress ECGs** in which the patient is taken close to maximum heart rate by exercising, for example on a treadmill. Changes in the ECG waveform during this process give the cardiologist indications as to the efficiency and capacity of the heart's pumping action. PVCs may only occur when the body is under physical stress, as this makes demands for higher cardiac output. Exercise testing can also be used to assess the effectiveness of therapeutic and surgical treatments.
A more specialised application of ECG analysis is the detection of *foetal distress* prior to and during labour. An additional problem here is the separation of the maternal and foetal ECGs (adaptive filtering techniques are usually required, in addition to careful positioning of the electrodes).

Foetal monitoring is now routine in the developed world, and the timing of dips in the foetal heart rate in relation to the mother's contractions, as well as the amplitude of the dips, are thought to be important indicators of foetal state. Similarly, changes in the level of the S-T segment may give an indication of low oxygen supply to the foetus (*foetal hypoxia*). Other research has concentrated on monitoring foetal heart rate variability, low variabilities having been shown to correlate with foetal distress (a high degree of variability would seem to indicate that the foetus' thermoregulatory control processes are working properly).

All the above applications involve the analysis of the ECG waveform and the extraction of various features of the waveform. In each case, the heart rate provides information of value and needs to be calculated. There are two types of heart rate meters (also known as *cardiotachometers*):

- the *averaging* heart rate meter which calculates the average heart rate from a count or estimate of the number of beats over a period of time;
- the *beat-to-beat* heart rate meter which computes the reciprocal of the time interval between two consecutive heart beats and updates the information with each heart beat.
Heart rate meters

The easiest way to obtain the heart rate (usually given as beats per minute) is to count some identifying feature of the ECG. The most easily distinguished feature of the ECG is clearly the QRS complex, which is a sharp spike.

![Figure 8: Effect of motion on ECG recording](image)

There are 3 main problems in detecting the QRS complex:
- artefacts due to electrode motion (as shown in Figure 8)
- baseline wander (mainly due to breathing)
- T-waves with high frequency content

These problems can be considerably reduced by passing the ECG signal through a band-pass filter. Spectrum analysis of the ECG signal reveals that most of the frequencies present in the QRS complex lie near 20 Hz and hence a filter with a pass-band of, say, 10 to 40 Hz should maximise the QRS energy.

The circuit of Figure 9, which would be equally applicable to averaging or beat-to-beat meters, could be used to generate pulses coincident with the R-wave of the ECG waveform. The threshold circuit triggers the
pulse generator when the band-pass filter output exceeds a preset threshold level. The pulse width should be greater than the Q-S interval so that only one pulse can be generated per QRS complex. The pulse train can then be fed to either of the circuits of Figure 10 or Figure 11, depending on the type of heart rate meter required.

**Figure 9: R-wave pulse generator**

**Averaging heart rate meter**

An indication of the average heart rate can be obtained by feeding the R-wave pulses to the input of a low-pass filter, which determines the "average power" of the pulse train (and hence the pulse repetition frequency since the pulses are of constant width and amplitude). The higher the heart rate is, the larger the charge which builds up on the capacitor. The resistor also bleeds off some of the charge from the capacitor when there are no pulses at the input, giving the sawtooth waveform shown in Figure 10. The time constant of the R-C circuit should be several beats long (between 5 and 15 seconds, typically) to minimise the output ripple.

**Figure 10: Low-pass filter for pulse counting in averaging heart rate meter**
**Beat-to-beat heart rate meter**

This computes the time between each beat and inverts it, giving an instantaneous heart rate. The circuit and timing diagrams for such a meter which uses digital techniques to compute the heart rate to 12-bit accuracy are shown in Figure 11.
The leading edge of the R-wave pulse (from the circuit of Figure 9) triggers the first mono-stable, giving a pulse of 10 μs width, for example. The falling edge of this 10 μs pulse in turn triggers the second monostable.

The counter counts the clock pulses between consecutive R-wave pulses. Monostable 1 causes the contents of the counter to be loaded into the latch; monostable 2 then resets the counter to zero in readiness for the next cycle. The maximum clock frequency is set by the length of the monostable pulses as the load and reset pulses must take less than one clock cycle in order to maintain the specified accuracy.

The outputs of the latch are taken to a multiplying digital-to-analogue converter (DAC). The output voltage is proportional to the reference voltage multiplied by the reciprocal of the number of clock pulses in one period of the input signal.

**Heart rate variability**

Under resting conditions, the ECG of a healthy individual exhibits periodic variation in the R-R interval. This phenomenon, known as respiratory sinus arrhythmia (RSA), fluctuates with the phase of respiration – acceleration during inspiration, deceleration during expiration. During expiration, the vagus nerve is stimulated, which slows down the heart rate (the right vagus innervates the sinoatrial node and acts on it). During inspiration, the vagus nerve is not stimulated.
Electroencephalography

In addition to ECG measurements, biopotentials can also be recorded from the brain (electroencephalography - EEG) or from muscles (electromyography - EMG). Electroencephalography has found many clinical uses, from the investigation of epileptic fits to sleep studies or the diagnosis of brain death. The EEG is the summation of neural depolarizations in the brain due to stimuli from the five senses as well as from normal brain activity. On the surface of the brain, these potentials are of the order of 10 mV; the amplitude of the EEG signal recorded with scalp electrodes, however, is 100 μV, at most, because of the attenuation caused by the skull.

EEG instrumentation is much the same as that used for recording the ECG, except that circuit design is even more critical because of the lower amplitude of the EEG signal. The frequency response of EEG differential amplifiers usually extends from 0.1 to 100 Hz.

EEG electrodes

The EEG is measured with Ag-AgCl electrodes which are placed in standard positions on the skull, at regular intervals along three lines: one from the nose to the back of the head, one from ear to ear and one around the circumference of the skull (see Figure 12).
Characteristics of the EEG

The frequency content of the EEG varies with the state of alertness and mental activity. To assist in EEG analysis, the normal EEG range of 0.5 to 30 Hz has been subdivided into five bands (note, however, that there is some degree of variation in the exact cut-offs from one system to another):

- **Delta** $\delta$ 0.5 - 4 Hz
- **Theta** $\theta$ 4 - 8 Hz
- **Alpha** $\alpha$ 8 - 13 Hz
- **Beta** $\beta$ 13 - 22 Hz
- **Gamma** $\gamma$ 22 - 30 Hz
What does the EEG look like in different brain states? Figure 13 shows the EEG through various stages (or depths) of sleep. The lower trace shows that, if the subject is dreaming, the EEG exhibits rapid, low-voltage waves that resemble those obtained in alert subjects (rapid-eye-movement or REM sleep). During the transition from REM to non-dreaming (deep) sleep, the EEG sometimes exhibits bursts of alpha-like activity, called spindles. These are periodic waves which have a frequency between 12 and 14 Hz and an amplitude of around 10 μV.
They last between 0.5 and 1 second but no-one has yet come up with a satisfactory explanation for their origin.

**Diagnostic uses of the EEG**

The main clinical purpose of the EEG is to help physicians diagnose disease. The pathological states or diseases usually diagnosed using the EEG are brain death, epilepsy and sleep disorders. The sustained absence of EEG signals is a clinical measure of brain death and the EEG can also be used as one of the indicators for deciding to carry out an organ transplant.

The pathological EEG during tonic-clonic seizures (formerly known as *grand mal* epilepsy) is characterised by high-magnitude synchronous waves of about 10 Hz. Absence seizures (formerly known as *petit mal* epilepsy) exhibit a spike and slow-wave pattern with a repetition frequency of about 3 Hz. Figure 14 shows the EEG waveforms recorded from different sites during one such seizure.
Evoked Potentials

This is a technique whereby a stimulus, such as a light flash or loud click, is applied to the body’s sensory system and the change in the EEG signal recorded from a particular area of the brain. Normal EEG activity, however, masks the brain's response to a single stimulus; repetitive stimuli have to be used and the evoked response is distinguished from the background activity by using the technique of signal averaging.