Application Note # 291491
Single arm ECG measurement using EPIC

Purpose

This application note describes a method for measuring ECG (ElectroCardioGram) signals from a single arm using Plessey Semiconductors' Electric Potential Integrated Circuit (EPIC) sensors. This enables continual heart monitoring without the need for chest straps or contact points on both sides of the body.

Introduction

EPIC is an electrometer capable of sensing ECG signals through insulated sensors in contact with the skin. The sensors are dry-contact, so that the gels or other contact-enhancing substances normally associated with wet-electrode ECG pads are not necessary. The signal is obtained by differentially amplifying the output of two sensors with high common mode rejection.

Applications for measuring ECG signals using EPIC thus far have required contact points from both sides of the body, i.e. either side of the heart.

For applications that require continual monitoring of heart rate – for example during exercise or longer term cardiac monitoring for those with heart problems – it is advantageous to be able to take signals from just one arm, thus avoiding cumbersome wiring across the body or the need to touch a wrist-mounted sensor with opposite hand [1].

Single Arm Application

As stated by Yang et. al. [2], cardiac signals strong enough to be differentiated from background noise exist in the upper arm.

Figure 3 shows signals from two EPIC sensors mounted on the upper left arm. The sensors are positioned such that the electrical cardiac signals are out of phase, hence giving a strong differential signal and thus good signal to noise ratio. The traces from the individual sensors and the differential are shown in figure 3. Signals have been bandpass filtered to remove unwanted noise artefacts.

Sensor positioning

There are three main considerations in terms of sensor positioning that affect the quality of the ECG signals that can be achieved from a single arm.

1. Choice of Arm

Figures 3 and 4 show traces obtained from pairs of sensors in approximately the same positions on the left (fig 3) and right (fig 4) arms of the same subject. The plots are shown side by side and on the same scale for easy comparison. Although the heartbeat is clearly detectable from the sensors on the right arm, the magnitude and quality of the signals are far superior with sensors mounted on the left arm (i.e. nearer the heart). Positioning sensors on the left arm is therefore recommended.

2. Distance from shoulder

The magnitude of the cardiac signal decreases significantly as the sensors are moved down the arm, away from the shoulder. The signals shown in figure 4 were measured with the sensors positioned 2-3cm below the armpit. The QRS region of the differential signal has an amplitude of approximately ±30mV (x10 external gain). Moving the sensors 3cm further down the arm reduces this peak to peak signal by about half to around ±15mV. Sensors should be positioned as far up the arm towards the shoulder as possible.

3. Position around the arm

Signal quality is significantly affected by where the sensors are situated around the arm. There are two primary considerations

a) Signal strength and phase.
   Signal strength varies considerably as the sensor positions are moved around the arm. As already stated, out of phase signals can be detected by appropriate positioning of the sensors, leading to the best differential signal.

b) Unwanted signal rejection
   The major unwanted signals in this case are the electrical signals produced by the muscles that control arm movement (pectoral, deltoid etc.). The strength of these electromyographic (EMG) signals varies around the arm.
   In some positions the EMG signal from active muscles is significantly larger than the cardiac signal, completely obscuring it. By changing the sensor location the EMG signal can be greatly reduced, allowing the cardiac signal to be seen above the background EMG "noise".

The sensor locations that give the largest amplitude cardiac signal from an arm with relaxed muscles will not necessarily give the best EMG rejection, and so the optimum sensor positioning will depend on the requirements of the application. Figures 5 and 6 show the relative strength of cardiac and EMG signals in different sensor locations as the wearer's arm is raised.

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The best position for EMG rejection when the muscles are active has been found to be on the underside of the arm, close to the armpit, as shown in figure 1a. If the desire is to measure cardiac signals only in a stationary, relaxed arm, a stronger signal can be obtained by moving the sensors as shown in figure 1b. However, the signal in this position will be swamped by the EMG signal if the muscles are used – for instance to move the arm or hold the arm in a raised position.

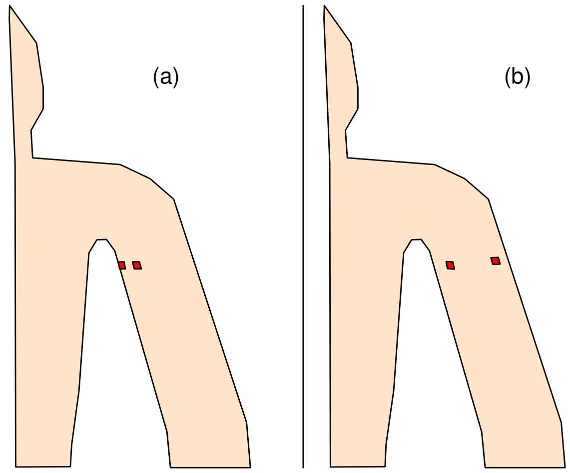

Figure 1. Sensor positions on upper arm for best rejection of EMG signals (a), and strongest cardiac signals (b).

For some applications there may be value in using more than two sensors mounted in different positions around the arm to obtain more information from the signals under a wider range of conditions.

Single arm ECG from a moving subject

The results presented thus far are from a subject who is basically stationary, apart from raising of the arm on which the sensors are mounted, as discussed.

The ability to take cardiac signals from sensors mounted on one arm allows the possibility of heart monitoring during normal daily activities, or during exercise.

Signals have also been measured from EPIC sensors mounted on the upper arm, whilst the subject is walking at a brisk pace. Results shown in figure 6 demonstrate that the heartbeat signal can be detected by differential amplification of the noisy signals, even with the minimal signal processing (i.e. simple bandpass filtering) used here.

Implementation

The traces shown in this application note have been collected using metal can EPIC sensors (Plessey part number PS25101) mounted onto a commercially available sports armband mobile phone holder as shown in figures 8 and 9. Signals were processed using the hardware and software from the standard EPIC demonstration kit.

It is envisaged that a commercial implementation of this technology would use the smaller compact EPIC sensors (Plessey part number PS25201), built into an armband that also contains the electronics necessary for amplifying, filtering and transmitting (via Bluetooth or similar) the signals. If – as in this case – the armband also serves as a mobile device holder (e.g. a SmartPhone) the data could easily be processed, stored and displayed on that device with a suitable software app. Alternatively the Bluetooth signal could be sent to a wrist-mounted sports watch or other remote device (see figure 2).

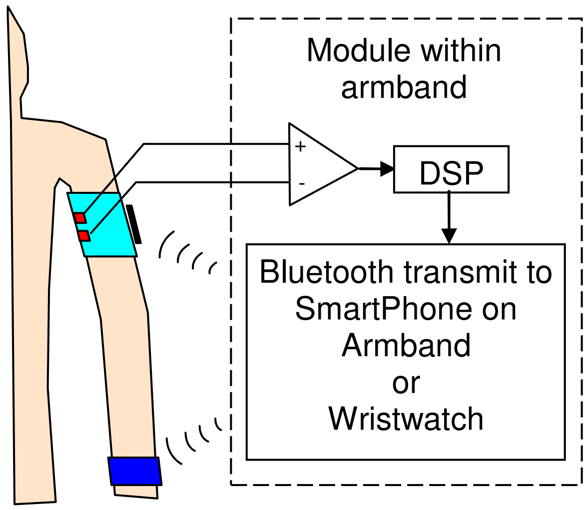

Figure 2. Representation of implementation using either a SmartPhone or wristwatch to receive the output

Conclusion

This application note has demonstrated that EPIC sensors are capable of measuring ECG-type signals from sensors mounted on a single arm, with no need for contact points on other parts of the body.

By appropriate positioning of the sensors and differential amplification, rejection of unwanted signals from muscles or movement can be achieved, enabling signals to be measured during movement or exercise.

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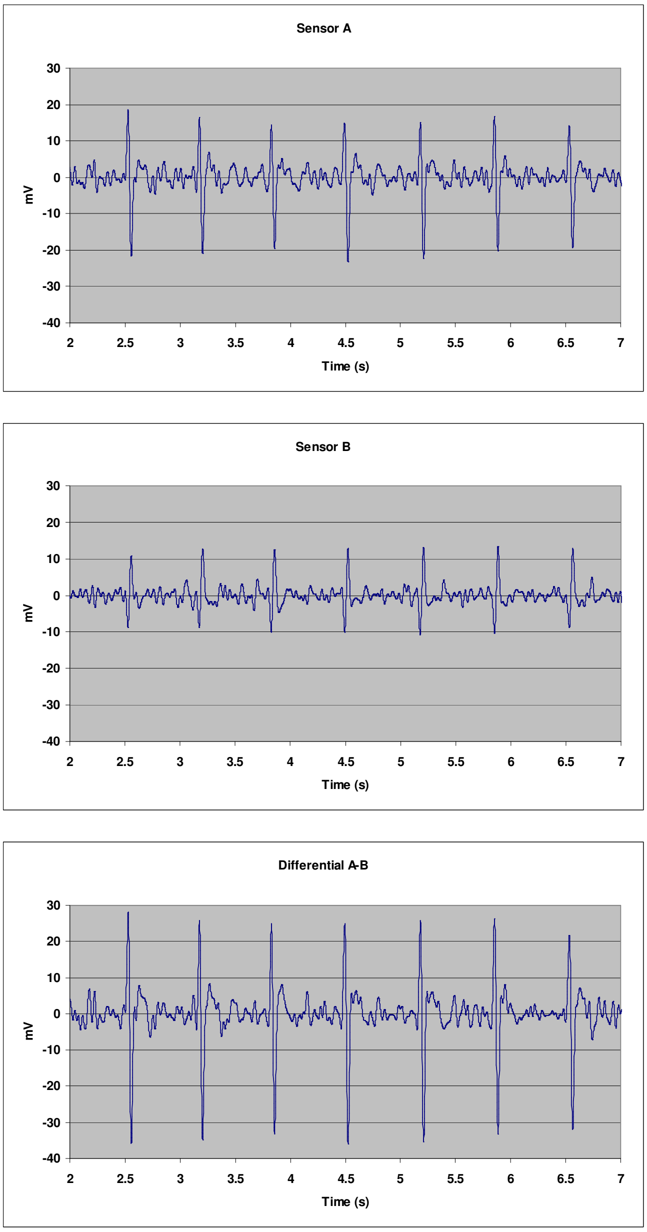

Figure 3 – ECG signals from sensors mounted in a sports armband on the left upper arm from a stationary subject. The graphs show the individual sensor outputs and the differential output, as labelled.

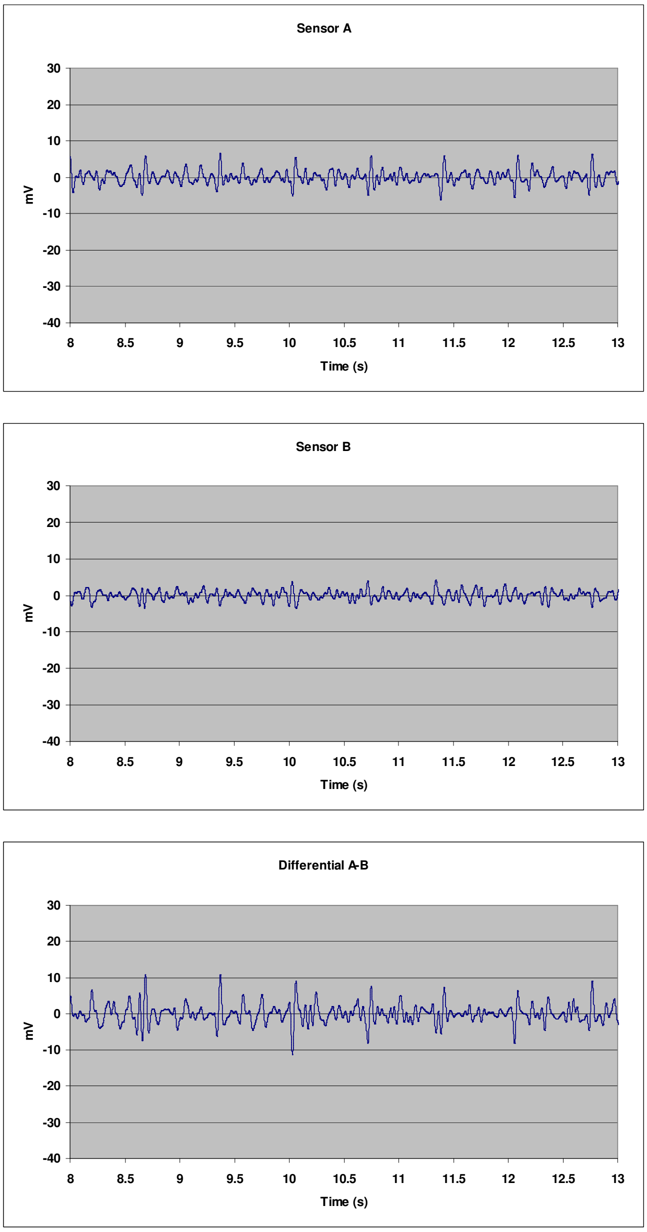

Figure 4 – ECG signals from sensors mounted in a sports armband on the right upper arm from a stationary subject. Scales are as for figure 3. The graphs show the individual sensor outputs and the differential output, as labelled.

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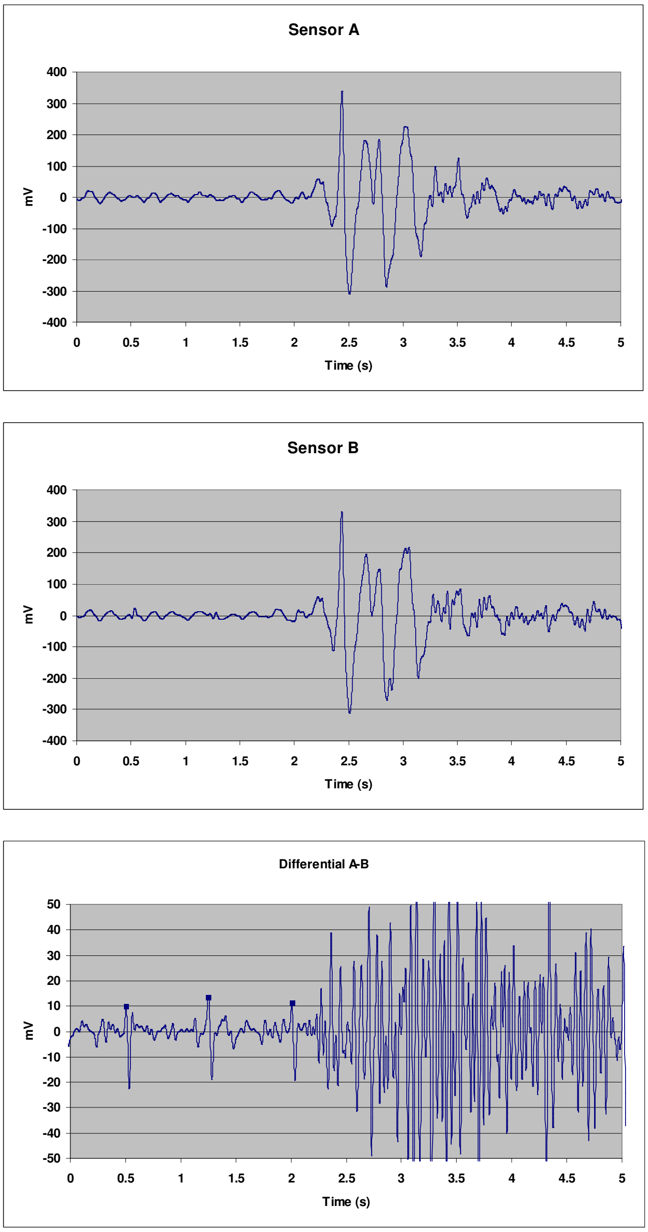

Figure 5 – ECG signals from sensors positioned on the top side of the left upper arm (as shown in fig 1b). The arm was raised after 2.1 seconds. The EMG signals completely mask the ECG signals.

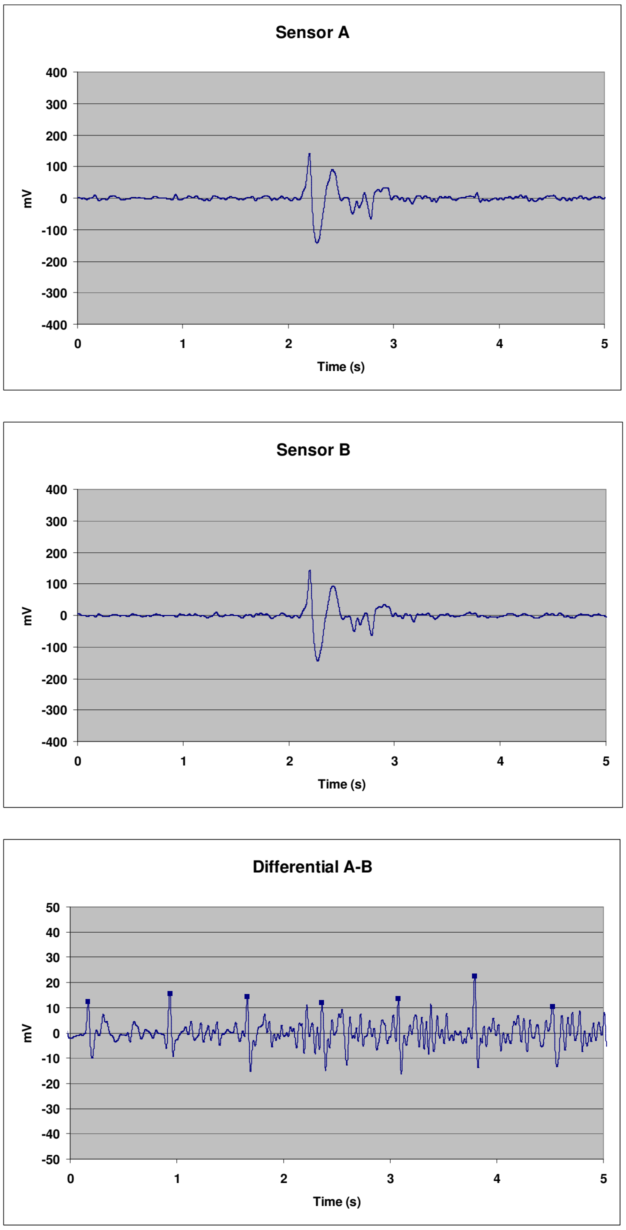

Figure 6 – ECG signals from sensors positioned on the underside of the left upper arm (as shown in fig 1a). The arm was raised after 2.1 seconds. The EMG signals are much smaller than in figure 5 because of the different sensor location on the arm, such that the position of the cardiac signals can still be clearly seen.

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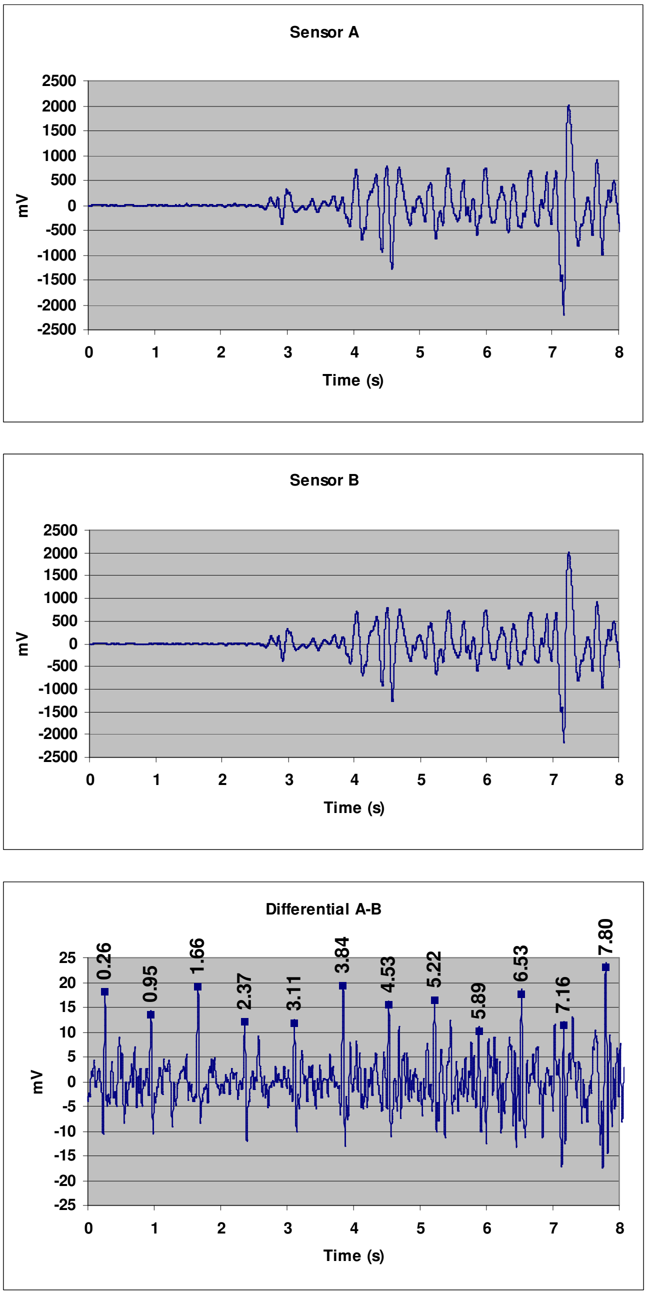

Figure 7 – ECG signals from sensors mounted in a sports armband on the left upper arm of a moving subject. The subject began walking after 2.5 seconds, as shown by the increase in signal amplitude on the individual sensors. Note that the y-axis scale is 100 times smaller for the differential trace (bottom)as the large common mode signals are rejected by the differential amplifier. The times corresponding to the QRS part of the ECG signal are shown on the differential trace.

Figure 8 – PS25101 sensors mounted on a commercially available Sports Armband mobile

Figure 9 –Sports Armband in position. Sensors are in contact with the underside of the arm, adjacent to the armpit

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References:
[1] Plessey Semiconductors' Application Note # 291465: *ECG using wrist-mounted EPIC sensors – available at www.plesseysemiconductors.com*

[2] Hung-Chi Yang, Tsung-Fu Chien, Shang-Hao Liu, Hsuan-Han Chiang, (Dept of Electrical Engineering, Southern Taiwan University): *Study of Single-Arm Electrode for ECG Measurement Using Flexible Print Circuit*

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Application Note 291491 issue 1

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