Purpose

This application note describes a method for measuring Electrocardiogram (ECG) signals without contact to the subject's skin. This is achieved using Plessey Semiconductors' Electric Potential Integrated Circuit (EPIC) sensors along with a driven circuit, all capacitively coupled to the subject's body through clothing. A design for the driven circuit is included, along with example ECG traces.

Introduction

EPIC is a capacitive sensor and so does not rely on ohmic contact to the body for measuring bio-electrical signals. It therefore has the ability to measure ECG without direct skin contact. Signals measured on the human body always include a large amount of noise, the major component of this being 50 or 60 Hz power line noise capacitively coupled to the body from the mains electricity supply. Measurements such as ECG depend on being able to extract the small electrophysiological signals from the much larger noise signals.

When using EPIC in "contact mode" for ECG measurement, the subject touches both the capacitive electrode surface and some metal at the system ground directly with the skin. This ground reference allows filtering and differential amplification of signals from two sensors to be effective in removing the mains frequency noise, leaving a high quality ECG signal

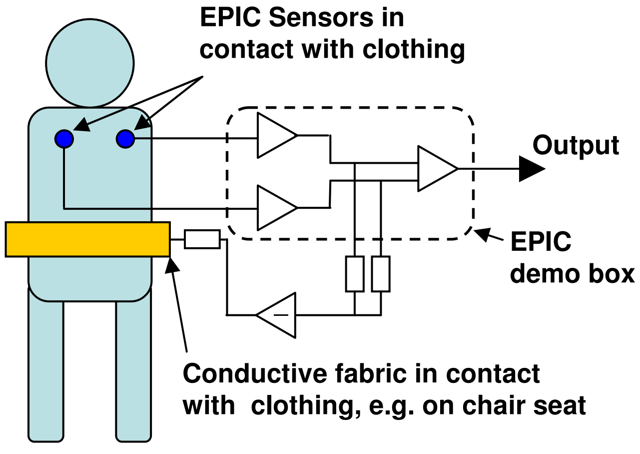

Figure 1 – Basic configuration for non-contact ECG measurement including capacitively-coupled DR" circuit.

In non-contact ECG measurement there is – by definition - no skin contact, and thus no direct connection can be made between the subject's body and the system ground. Some other method of reducing the power line noise is therefore required to enable the ECG signal to be extracted reliably and accurately. One such method utilises an approach very similar to the Driven Right Leg (DRL) system that is used for the same purpose in conventional ECG. In conventional ECG the DRL signal is coupled directly to the patient's skin; in non-contact ECG it is coupled capacitively to the body, through clothing, via a piece of conductive material placed – for instance – on the seat or back of a chair. Capacitive coupling of DRL signals is described by Lim et al [1] and Lee et al[2].

System design

This application note will describe a system built into a chair as a specific example, although the techniques can be readily adapted for a system built into a mattress or clothing and so forth.

The DRL circuit reduces power line noise on the sensor signals by feeding back an inverted average of the signals from two sensors onto the body, as shown in figure 1. Referring to figure 1, the EPIC sensors are mounted on the chair back such that the electrodes touch the clothing on the subject's back when resting normally against the chair back. The DRL signal is connected to a piece of conductive material placed either on the seat of the chair, or at the bottom of the chair back, such that it will contact the subject's clothing in normal sitting position.

Both copper-coated nylon fabric and aluminium foil have been used successfully for the DRL coupling material; it is expected that other conductive materials will be equally suitable. A thin, non-conductive material may be used to cover both the sensors and the DRL coupling fabric if required (for instance when building the sensors into a seat), although consideration should be given to how the choice of material will (a) reduce the coupling capacitance between the sensor and the subject, and (b) add additional noise to the signals through static charging effects. Cotton fabric is one suitable choice.

Figure 2 shows the design of the DRL circuit. It is a standard summing amplifier, generating an amplified and inverted signal that is the average of the individual signals A and B.

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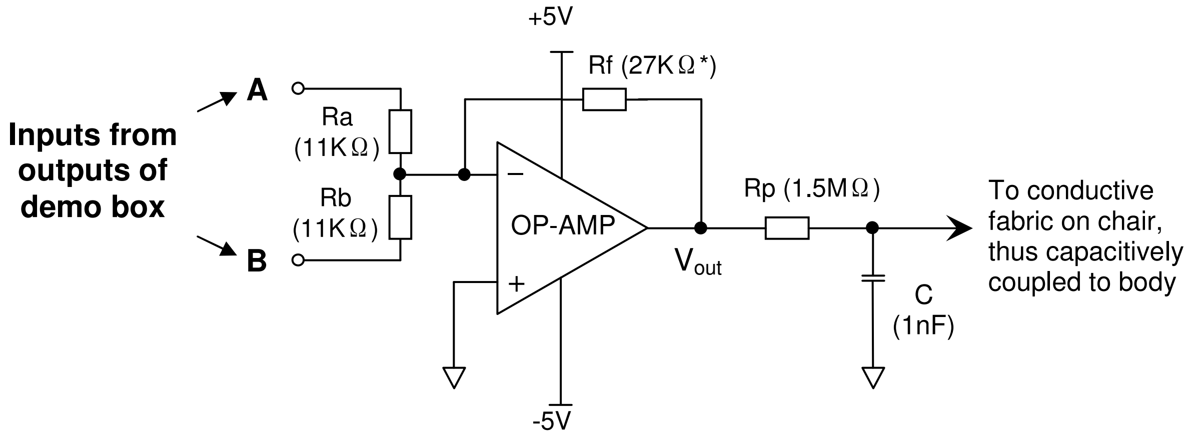

Figure 2 – DRL circuit. Voltage gain is set by Rf; Rp limits current fed back to the body (see text).

The output (V_{out}) of the operational amplifier is given by:

$$V_{out} = -(V_A + V_B) * \frac{Rf}{11K}$$

The optimum value for Rf will be dependant on the type of sensors being used, as well as the clothing being worn by the subject being measured. It should be set to achieve maximum noise reduction, whilst ensuring circuit stability. A value of 27KΩ is suggested as a suitable starting point for all EPIC sensors.

Rp, the protection resistor, is included to limit the current that can be fed back to the human body. This resistor is essential in ensuring that the subject's well-being is not endangered and must not be omitted. **Please read the section headed "*Safety Considerations*", before using this circuit.**

Implementation

The demonstration of non-contact ECG is best performed using an EPIC demonstration kit, Plessey part no. PS25000 (50Hz notch filter) or PS25001 (60Hz notch filter). The inputs to the DRL circuit can be taken from the BNC outputs "A & B" on the front of the demo box. The DRL circuit will require its own bipolar power supply: ±5V or ±6V is suggested. A circuit design including a battery power supply is shown in figure 3.

Compact sensors (Plessey part numbers PS2520x) and disc sensors (PS25101) provide equally good results, although for demonstration purposes, disc sensors are easier to fix to a chair to make contact with the occupant's back than compact sensors mounted on the PS25014A application board. If using PS25014A boards, they should be mounted horizontally, with the connector housing just to the side of the subject's back such that the subject will make contact with the electrodes (through clothing) when sitting normally in the chair. Compact sensors are recommended if designing a custom-built system.

EPIC sensors designed for contact electrophysiology sensing (part nos. as above) have given excellent results in most cases. Initial trials suggest that modifications to the sensor design (e.g. lower gain and higher input impedance) can offer increased sensitivity and thus the ability to detect weaker ECG signals. Please contact Plessey Semiconductors for advice on the latest sensor design for this application.

The shape of the ECG trace that is measured – in terms of relative magnitudes of the P, Q, R, S and T waves – will depend on the positioning of the sensors behind the subject's back. If the desire is only to measure the "R-R" interval to determine heart rate, then the siting of the sensors is not critical. Placing one sensor either side of the spine, separated by 6-10 inches (15-25 cm), at approximately the same height as the heart is recommended as a starting point. For applications where signals from other parts of the cardiac cycle are required the user should refer to texts on bioelectronic signals for guidance on sensor position.

The following hardware and software settings are recommended as starting values for system evaluation or demonstration. These may need to be adjusted, as the strength of ECG signals will always be dependant on the physiology and clothing of the person being measured.

Demo box settings

- Low Pass filter: IN
- Gain : x10 for sensors with x10 gain
x1 for sensors with x50 gain
- Notch filter: IN

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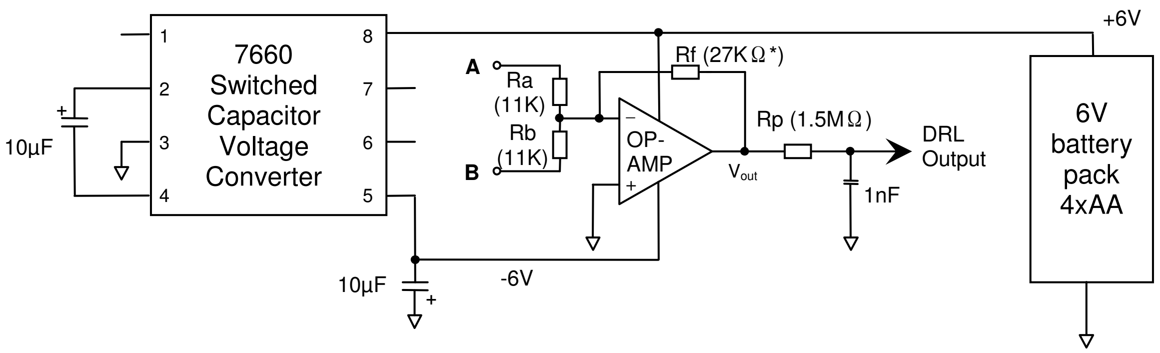

Figure 3 – DRL circuit including battery power supply and voltage converter to provide -6V rail.
Inputs A and B are buffered outputs from the sensors and may be taken from the A and B outputs of the EPIC demo box. Ground should be connected to the sensor 0V, the shielding of the BNC A & B outputs on the demo box being a suitable connection point. See figure 2 and the text for further comments on the DRL design.

Software settings

- Voltage scale: 10mV or 50mV
- Time base: 0.5s/div
- HP filter: Selected, 8Hz **
- Comb filter: Selected, N=6, Q=25
- LP filter: Selected, 25Hz **

** High and low pass filter frequencies of 8 and 25Hz will remove much of the disturbance to the signal caused by breathing etc. and can be ideal for showing the "R-R" interval of the cardiac cycle. Wider filter settings, for instance up to the HP=50mHz and LP= 150Hz values required by medical ECG, can be used. Figures 4 and 5 show traces using two different filter settings. Note that the "R-R" interval is unaffected by the filter settings, but the overall shape of the measured trace can be changed significantly.

Hints

The following pointers may be useful when using the techniques described in this application note for measuring non-contact ECG signals.

1. Settling time – When a subject first sits in the chair and leans against the EPIC sensors, the changes in electric potential will normally send both the sensors and the DRL circuit into saturation. Because the system contains some large impedances, and hence has some very long RC time constants, settling times of tens of seconds can be needed before a clean ECG signal is seen. During this period the signal can either appear very noisy, or be virtually flat, depending on whether one or both sensors, or the DRL circuit, are "railing". The subject should sit still during this time and wait for the circuit to settle, since continually adjusting position will only make matters worse. Settling times can sometimes be reduced by turning off the power to the demo box for a few seconds.

2. Clothing – Best results have been obtained when the material between the sensors and the skin is one or two layers of cotton material. This is therefore recommended as a starting point for system evaluation. Signals have also been measured successfully through other materials, including a wool-mix sweater and a polyester fleece in addition to two layers of cotton material. Examples are shown in figures 6 and 7. If the key parameter of interest is the "R-R" interval, adjustment of filter settings to reduce or re-centre the signal bandwidth can give significant improvement in signal quality.

3. Static – Because there is no direct physical contact between the subject and any grounding point, there is no path for any static build up to be discharged. Under most circumstances static build up does not present a problem, but depending on factors including clothing, footwear, flooring, humidity levels in the air and so forth, static build up can sometimes prevent the cardiac signal from being seen clearly. In this situation the subject should briefly touch something metal connected either to an external ground or to the system ground to discharge the static.

4. Cable shielding – The EPIC demo box grounds the shielding of the sensor cable via the connection between the outer casing of the sensor plugs and the metal surround of the socket on the box. Ensuring that this connection is well made will reduce unwanted noise artefacts from the signal.

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Conclusion

This application note has described how EPIC sensors can be used to measure ECG signals without physical skin contact. Although reference has been made to sensors embedded in a chair or seat, the techniques are equally applicable to sensors mounted on a mattress, in clothing or in other situations.

There are many variables that will affect signal quality, from the strength of cardiac signal generated by the individual being measured, to clothing, to the surrounding environment. The user is therefore encouraged to use the designs given here as a starting point in establishing an optimum system for a particular application.

Safety considerations

The currents required to interfere with the electrical activity of the human heart are – to the layman – surprisingly low. For instance, the American Heart Association published a discussion document in 1996[3] recommending that "ECG risk currents be limited to 10 µA through patient-connected leads." Maximum safe current limits for any devices that are to be connected to the human body are specified in national and international standards. The widely accepted international standard is IEC 60601; some national variations exist.

Before using the DRL circuit, the user must ensure that any circuit that is to be coupled to the human body complies with the latest Medical Equipment Safety regulations, under both normal and potential fault conditions, in the country in which it is being used .

References:

[1] YG Lim, GS Chung, KS Park. "Capacitive Driven-right-leg Grounding in Indirect-contact ECG Measurement," *32nd Annual International Conference of the IEEE EMBS Buenos Aires, Argentina, August 31 - September 4, 2010 pp 1250-1253*

[2] KM Lee, SM Lee, KS Sim, KK Kim, KS Park "Noise Reduction for Non-Contact Electrocardiogram Measurement in Daily Life," *Computers in Cardiology 2009;36: pp 493–496*

[3] MM Laks, R Arzbaecher, JJ Bailey, DB Geselowitz, AS Berson. "Recommendations for Safe Current Limits for Electrocardiographs" *A Statement for Healthcare Professionals From the Committee on Electrocardiography, American Heart Association, 1996*

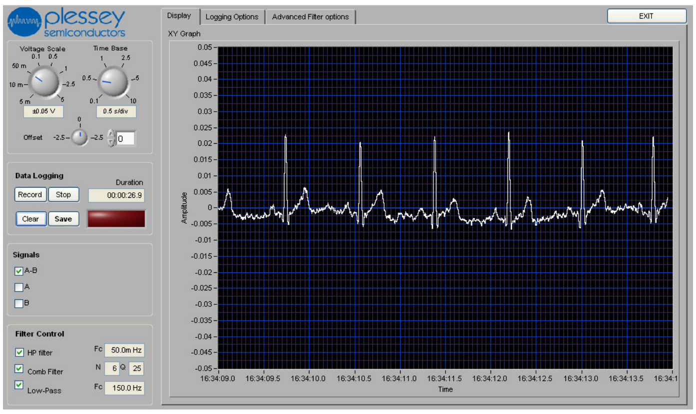

Figure 4 – Non-contact ECG signals measured through a single layer of cotton clothing, with a capacitively coupled DRL circuit. HP filter corner frequency is 50mHz, LP filter in demo box has corner frequency of 30Hz.

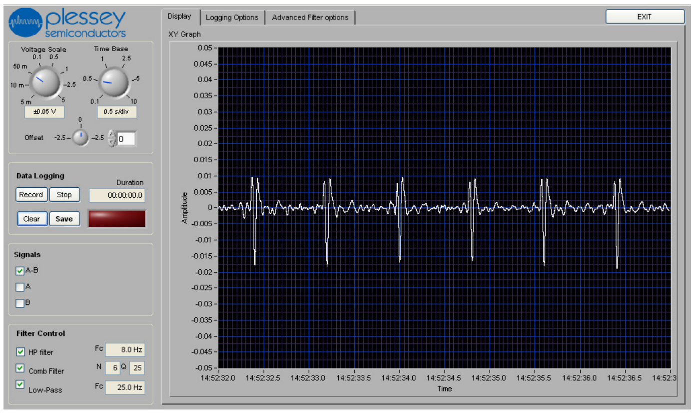

Figure 5 – Non-contact ECG signals measured through a single layer of cotton clothing, with a capacitively coupled DRL circuit. Software filters limit the bandwidth to 8-25Hz.

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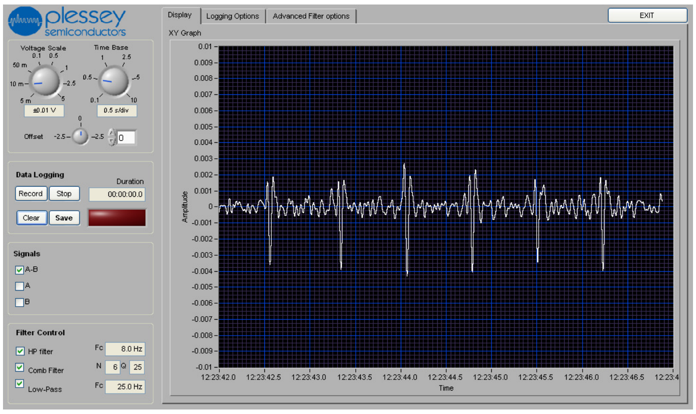

Figure 6 – ECG signals measured from a subject wearing a wool-mix sweater over a cotton shirt. Sensors attached to the chair-back were covered with an additional layer of cotton material. Filter settings limit the bandwidth to 8-25Hz. The heart rate can be easily extracted.

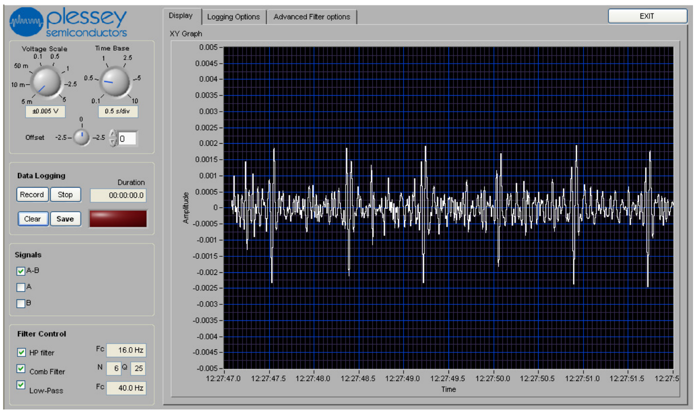

Figure 7 – ECG signals measured from a subject wearing a polyester fleece over a cotton shirt. Sensors attached to the chair-back were covered with an additional layer of cotton material. Filter settings limit the bandwidth to 16-40Hz. The heart rate can be easily extracted.

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