Non-contact ECG measurement using EPIC Sensors

Measuring electrocardiogram (ECG) signals without skin contact is possible using novel Electric Potential Integrated Circuit (EPIC) sensors.

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Introduction

The human heartbeat is arguably the single most important ("life-and-death") diagnostic indicator. Thus electrocardiograms (ECGs) are one of the most significant diagnostic methods in that they monitor heart function. ECGs are not only used in a clinical setting but are increasingly seen in personal health devices. Traditionally, ECG measurement conductive electrodes have been applied which are directly attached to the skin. With the help of contact gel (wet or solid) to ensure that there is good electrical contact between the skin and the sensor, direct resistive contact is made with the patient. However, conventional electrodes possess various disadvantages which are not conducive for long-term use in non-clinical settings. In addition to being potentially messy, metal allergies can cause skin irritations and, as a single-use item, they are quite expensive.

Non-contact measurement of electrophysiological signals is of great interest in healthcare settings, with the potential of reducing disposable costs, speeding up or simplifying measurement techniques. Monitoring long-term medical conditions within the home or observing pilots, drivers, soldiers, and others in safety critical situations is now possible without needing skin contact. Monitoring vehicle drivers for health and alertness by detecting heart rate and respiration, or determining car occupancy to adjust the ride, handling and air bag deployment with the varying size and location of occupants, is a vast potential market.

Capacitive (insulated) electrodes can register ECG signals without conductive contact to the body - even through clothes - and represent an attractive alternative for a wide range of new applications. **EPIC** (Electric Potential Integrated Circuit) is a completely new sensor technology resulting from research at the University of Sussex (UK). Novel, ultra high impedance EPIC sensors measure electric field changes without requiring physical or resistive contact. This award winning, patent-protected sensor can rapidly measure electric potential sources such as electrophysiological signals or even spatial electric fields. It therefore has the ability to measure ECGs without direct skin contact. By adjusting the DSP and amplification circuitry, the sensors can be tuned for detection at a distance as required for differing automotive applications. **EPIC** sensor electrodes can be easily and discretely incorporated inside car seat backs to acquire the necessary biometric data.

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 surrounding electricity supply. Measurements such as ECG depend on being able to extract the small electrophysiological signals from the much larger noise signals. EPIC sensors can be used in "contact mode" for ECG measurement, where 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. 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 utilizes an approach very similar to the "Driven Right Leg" (DRL) system that is used for the same purpose in conventional ECG measurement techniques. In conventional ECG the DRL signal is coupled directly to the patient's skin. The DRL signal reduces power line noise on the sensor signals by feeding back an inverted average of the signals from two sensors on to the patient's body. In non-contact ECG, the generated DRL signal can be capacitively-coupled 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 al¹ and Lee et al².

System design

An ECG system can therefore be built into a chair, a mattress, or clothing for instance. The DRL circuit improves the sensor signal/noise ratio enormously. In the example in Figure 1, EPIC sensors are mounted on a chair back such that the electrodes touch the clothing on the subject's back when resting normally against the back of the chair. The generated 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, contacting the subject's clothing in the normal sitting position. Copper-coated nylon fabric is one possible material suitable for the DRL coupling material, but other conductive materials may be equally successful. A thin, non-conductive

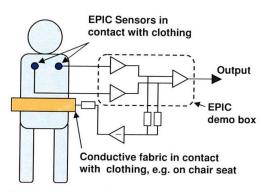


Figure 1 – Basic configuration for non-contact ECG measurement including capacitively-coupled DR" circuit

material such as a cotton fabric may be used to cover both the sensors and the DRL coupling fabric if required, for instance when building the sensors into a seat. Consideration must be given as to how material will reduce the coupling capacitance between the sensor and the subject, or add additional noise to the signals through static charging effects.

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.

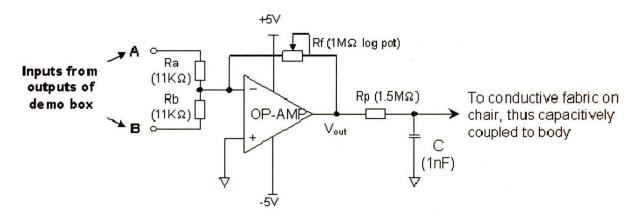


Figure 2 – DRL circuit. Voltage gain is set by Rf; Rp limits current fed back to the body (see text).

Operational amplifier output Vout = - (VA + VB) * $\frac{Rf}{11K}$

The optimum value for Rf will be dependent on the type of sensors being used, as well as the clothing being worn by the subject being measured, as well as the background noise levels. Rf should be set to achieve maximum noise reduction, while ensuring circuit stability and is thus best implemented as a potentiometer.

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 wellbeing 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. PS25003, which includes the necessary drive circuitry and switchable 50Hz and 60Hz notch filters. 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.**

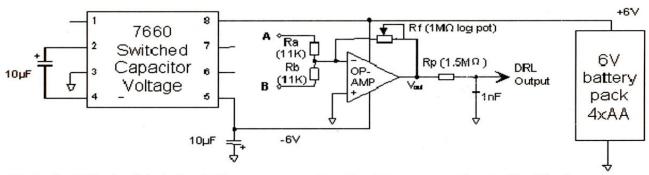


Figure 3 – DRL circuit including battery power supply and voltage converter to provide -6V rail. Inputs A and B are buffered outputs from the sensors and may be taken from the A and B outputs of the EPIC demo box. Ground should be connected to the sensor 0V, the shielding of the BNC A & B outputs on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

Plessey's compact sensors (PS2520x) and disc sensors (PS25101) provide equally good results, although for demonstration purposes, disc sensors are simplest to fix to a chair to make contact with the occupant's back. Compact sensors are recommended when designing a custom-built system.

EPIC sensors which are designed for contact electrophysiology sensing give excellent results in most cases. Initial trials suggest that custom modifications to the sensor design (e.g. lower gain and higher input impedance) can offer increased sensitivity and the ability to detect weaker ECG signals.

The shape of the measured ECG trace – 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 positioning 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 bio-electronic signals for guidance on sensor position.

The following hardware and software settings are suggested starting values for system evaluation or demonstration, but they may need to be adjusted, as the strength of ECG signals will depend on the variables of the target being measured. More sophisticated self-adjusting schematics can be envisaged for custom applications.

Demo box settings

Low Pass filter: ON
Notch filter (50/60Hz): ON

Gain: x10 for x10 gain sensors
x1 for x50 gain sensors

Software settings

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

HP filter: Selected, 8Hz **

** High and low pass filter frequencies of 8 and 25Hz remove breathing artifacts and are ideal for showing the "R-R" cardiac cycle interval. Wider settings (e.g. 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.

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.

Clothing

Good results can be obtained with one or two layers of cotton material between the sensors and the skin. Other materials, including a wool-mix sweater and a polyester fleece in addition to two layers of cotton material have been successful. Examples are shown in Figures 6 and 7. If the key greatest interest is in the "R-R" interval, adjusting filter settings to reduce or re-center the signal bandwidth can give improved signal quality.

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. Product design must take into account a discharge to the system ground to remove the static charge.

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. Careful shielding reduces unwanted noise artifacts.

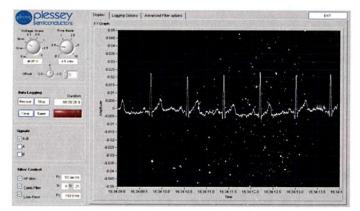


Figure 4 – Non-contact ECG signals measured through a single layer of cotton clothing, with a capacitively coupled DRL circuit. HP filter corner frequency is 50mHz, LP filter in demo box has corner frequency of 30Hz.

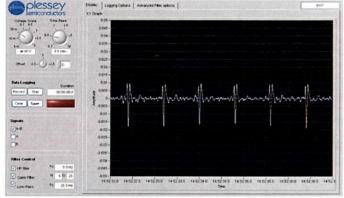


Figure 5 – Non-contact ECG signals measured through a single layer of cotton clothing, with a capacitively coupled DRL circuit. Software filters limit the bandwidth to 8-25Hz.

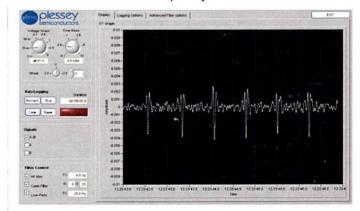


Figure 6 – ECG signals measured from a subject wearing a wool-mix sweater over a cotton shirt. Sensors attached to the chair-back were covered with an additional layer of cotton material. Filter settings limit the bandwidth to 8-25Hz. The heart rate can be easily extracted.

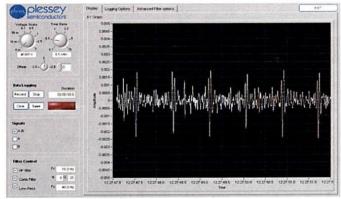


Figure 7 – ECG signals measured from a subject wearing a polyester fleece over a cotton shirt. Sensors attached to the chair-back were covered with an additional layer of cotton material. Filter settings limit the bandwidth to 16-40Hz. The heart rate can be easily extracted.

Conclusion

EPIC sensors can be used to measure ECG signals without physical skin contact. While sensors can be 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 surprisingly low. The American Heart Association published a discussion document in 1996³ 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