Letter to the Editor

On bio-activity related signals from contactless electrode measurements

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In a recent paper on a displacement current sensor for contactless detection of bio-activity related signals [1], it was stated that "*A potential means for human presence detection…is via sensing…human biopotentials*" [because] "*physiological events associated with the biological functions of many human organs produce electric fields,*" and that "*the ECG is relatively easier to measure compared to other biopotentials and, hence, can potentially provide an important* [underscore added] *means of detection of human presence*."

Contactless biopotential measurement using off-body electrodes has attracted many authors that have proposed various solutions, some of which are far more expensive than that devised in [1]. Usually, one or two aluminium discs at a few centimetres from the chest are connected to a high-impedance voltage amplifier and the large impedance between these electrodes and ground makes the circuit very susceptible to capacitive (electric-field) interference hence it requires electric shields or driven guards. Measuring displacement current instead of electrode voltage in contactless biopotential measurements, as proposed in [1], avoids high impedance nodes hence measurements should be far less susceptible to electric field interference. Consequently, it is stated in [1] that "[Contactless] *capacitive sensors therefore can be used to sense the displacement current induced by the time-varying electric fields associated with various human biopotentials*." This is in principle an interesting approach worth being considered and the authors deserve praise for that.

Nevertheless, for that approach to be successful no electric field larger than those created by biopotentials should exist around the human body or, if they exist, such as 50/60 Hz electric fields from power distribution lines, they should be conveniently filtered out. Otherwise, as reported in [2], "*small oscillatory* [electric-] *field perturbations* [near the human body] *will occur with each heart beat, coincident with each respiration, and in time synchrony with any other parameter which influences body-electrode proximity and net body charge.*" Variations of that coupling capacitance were the basis of the displacement cardiograph [3], also called "cardiokymograph," wherein the capacitance C_e between the sensing electrode and the body was part of an oscillator which amplitude was modulated by tissue displacements. The "charged body-proximity hypothesis" [2], *i.e*. the variation of the capacitance C_e at each heart beat was not considered in [1] in spite that "*the sensor head is formed using a thin aluminium disk with a lightly charged* [stress added] *dielectric layer attached to its front surface to enhance sensor's sensitivity*." This charged dielectric layer creates an electric field that will be distorted by body surface movements thus adding displacement current to the current created by the varying surface biopotentials. Other authors have placed a high-voltage conductor (1 kV) close to the body to create an electric field and obtained signals related to cardiac activity [4] but, in fact,

even stray charge collected by an ungrounded subject and variations in C_e can yield large damped electrode-potential oscillations that repeat at each heart beat [5], the same as the damped electric-field oscillations reported in [2].

It turns out that, whereas in the Abstract of [1] it is stated that the developed sensor showed "*a remarkable capability in measuring human's heart bio-activity related signals resembling ECG at off-body distance up to 0.4 m.*", the only evidences provided to support that statement are several recordings that show voltage peaks with the same rate as a simultaneous ECG, and the resemblance of those recordings to previous recordings obtained by other authors, with far more expensive electronic circuitry but similar electrodes, that also claimed their signals were attributable to the ECG but had neither considered the possible effect of the variations of C_e due to the beating heart.

In order to estimate to what extent the recorded signals were mostly due to body movements rather than to biopotentials, it is worth to analyse the equivalent circuit of the sensor in Figure 1 of [1]. There is a coupling capacitance C_e between the body and the electrode that forms a voltage divider with the input capacitance of the ensuing circuit (C_{in}). As a result, unless C_e is comparable or larger than C_{in}, the potential at the electrode will be much smaller than that of the body surface. A circular aluminium disc 5 cm in diameter, as used in [1], needs to be closer than about 2 cm to achieve $C_e \approx 1$ pF hence comparable to the input capacitance of the best operational amplifiers available in the market. For example, the PS25251 or PS25451 ultra-high impedance "ECG sensors" by Plessey Semiconductors have 20 GΩ in parallel with 15 pF (http://www.plesseysemiconductors.com/epic-plessey-semiconductors.php), which would largely attenuate the signal. That voltage divider effect appears even if the equivalent input resistance of the voltage amplifier is very large, say, 1 TΩ. This requirement of a very small input capacitance to avoid signal attenuation may be relaxed by measuring current, as proposed in [1], instead of measuring voltage as usual in the bibliography, but the equivalent input impedance of the transimpedance amplifier (TIA) should be analysed to assess the actual improvement. Anyway, measuring current does not avoid the dependence of C_e on the electrode-chest distance, and any change in C_e, for example due to precordial movements, will yield a variable displacement current through it. Therefore, it will be difficult to distinguish the effect of those movements from the variations of the surface potential due to the electrical activity of the heart (the ECG). If we assume C_e = 1 pF, and the peak ECG amplitude is 1 mV, at 10 Hz (maximal power of the ECG), the displacement current through C_e will be about 0.06 pA. Now, if the electrode is covered by a dielectric charged at, say, 100 V, and C_e changes at 1 Hz rate, the current through it will be about 60 pA, one thousand times larger than the current due to the ECG. Therefore, changes in the coupling capacitance will be far easier to detect than signals due to ECG potentials. Consequently, the statement in [1] that "*the technique here is conceptually related to the sensing methods employed in ac-feedback electrostatic voltmeter and chopper-stabilized field meters, whereby the electrostatic field at the sensing electrodes of these devices is detected with the help of mechanical modulators used to convert a dc field into an ac field*" is probably correct but not because "*the modulator is the time-varying electric field of the monitored biopotential, v_s, while the charged dielectric surface and its effectively free electrons provide an initial electrostatic field that is easily modulated by v_s.*" as argued in [1]. It seems more probable that the vibrating chest "modulates" the electric field created by the charged dielectric, i.e. changes the displacement current through C_e. In any case, the method is good to detect a beating heart at a short distance but the measurement is not passive as claimed, when it is stated that "[the sensor] *employs a safe passive signalling*

approach by monitoring readily available bio-activity and movement related to electric signals…"

Repeating the measurements without charging the dielectric would help in elucidating the actual origin (mechanical or electrical) of the signals detected: a lack of signal in the absence of charge in the dielectric, and in the body, would mean that the origin of the signal is mechanical rather than the ECG. Therefore, the conclusion that "*the developed sensor is highly suitable for the remote detection of human presence via sensing signals associated with both controlled and non-controlled electrophysiological signals* [underscore added] *produced by the human, such as those related to EMG and the ECG*" would be more correct if body movements, either voluntary or involuntary, rather than electrophysiological signals were identified as the basis for the detection.

The possible mechanical origin of signals related to cardiac activity in [1] would help in explaining the disagreement between some predictions from the design data and the noise results reported. The typical spectral density of the input current noise for the TL082 at 1 kHz, when supplied at ±15 V, is 0.01 pA/√Hz, hence if the transresistance is 10^8 V/A then the expected spectral density of the output voltage noise would be 10^{-6} V/√Hz but in Fig. 5(b) in [1], where the power supply is ±5 V, the result at 1 kHz is less than 10^{-7} V/√Hz. Regrettably, the manufacturer does not specify the impact of power supply voltage on current noise but if that current noise reduction by 10 were confirmed and held true for actual low-noise op amps, that would be a very simple technique to reduce electronic noise. Nevertheless, current noise for the AD824, which is also BiFET, just decreases from 1.1 fA/√Hz when supplied to ±15 V to 0.8 fA/√Hz when supplied to 3 V, and the TLC084-Q1, which is BiMOS, has the same current noise when supplied at 12 V and when supplied at 5 V. Therefore, reducing the supply voltage does not seem to guarantee a drastic reduction in current noise. Anyway, integrating the current noise of the TL082 from 0.5 Hz to 250 Hz gives a current larger than the 0.06 pA ECG peak current that we could expect for an electrode at only 2 cm from the body. Therefore, in the absence of chest movements or external electric fields, the signal from the ECG would be masked by electronic noise, what reinforces the hypothesis that precordial chest movements rather than the ECG may be the cause of the cardiogenic signal detected.

Finally, to optimize this approach to the contactless measurement of signals related to physiological activity with a portable system, some points should be clarified. First, the use of a resistive T-network is a well-known resource to replace large-value feedback resistors, but has a major drawback [6]: the noise gain increases by the same multiplying factor $(1 + R_2/R_1)$ that increases the apparent value of R_f (Fig. 3(b) in [1]). Second, the system response to ECG voltages is high-pass because the displacement current through C_e due to the ECG will increase with signal frequency. Therefore, even if C_e were somehow kept constant, the output signal should look like a derivative of average surface potentials in the area in front of the electrode rather than a surface ECG or a damped oscillation like the signals in Figs. 7(b) and (c). Third, the statement "*no electrical connections are made with the human body* [during the experiments]" contradicts that other one: "*we also show in Fig. 6(b) the corresponding on-body recorded ECG trace detected using a standard 3-lead Ramesy* [Ramsey] *ECG1C electrocardiogram monitor*." This device seems to be a conventional ECG monitor that uses wet electrodes in contact with the body. It should be verified whether "contactless" signals were affected or not by those body connections. Fourth, if movements are detected, respiration yields larger chest displacements than heart contraction hence they would be easily detected than

cardiogenic vibrations. Fifth, whatever the origin of the signal, if it arises because of changes in electric potentials it will disappear if a conductive shield is placed around the body. This could be a metal container or a metal foil wrapped around the torso.

References

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