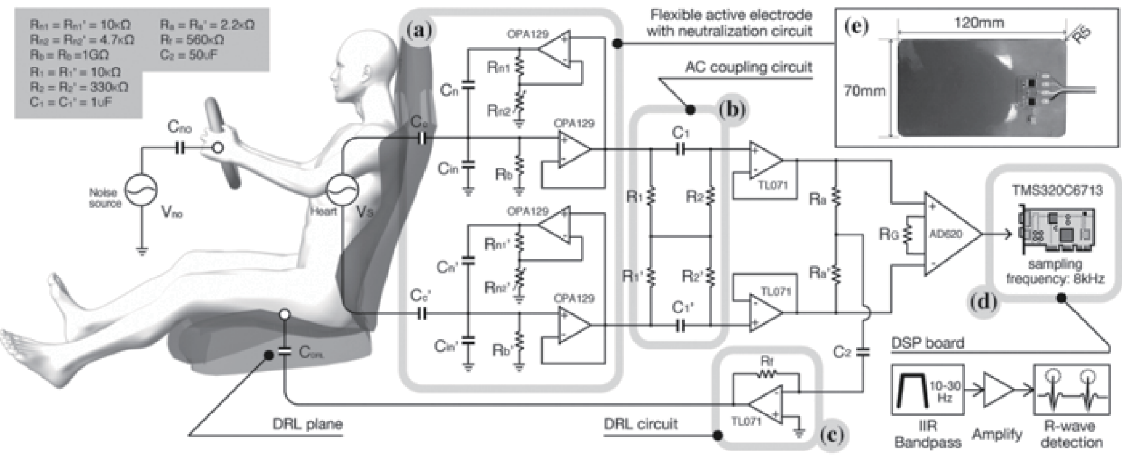

Fig. 1. Configuration of the cECG circuit. (a) Flexible capacitive electrodes with neutralization circuit. (b) AC coupling circuit. (c) DRL circuit. (d) DSP board. (e) Size of the electrode.

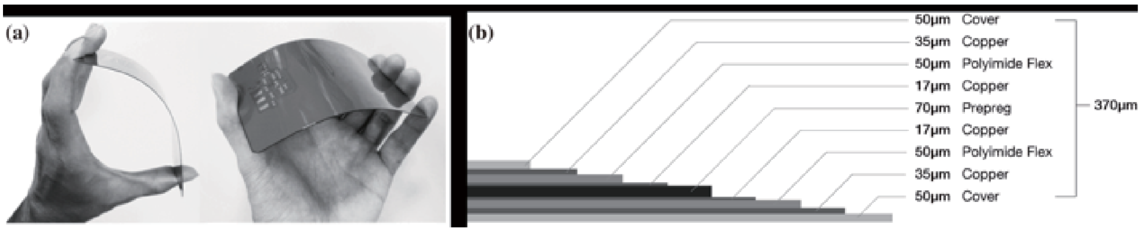

Fig. 2. Capacitive electrode. (a) Appearance of the capacitive electrode. (b) Cross section of the capacitive electrode.

a current that equals the current flowing on Cin, thus neutralizing the effect of this capacitance [8]. Another key to avoid signal attenuation is to make large Cc. Each electrode forms a coupling capacitance Cc with the driver's body, which is known to be: $Cc = \epsilon$A/d, where A is the effective surface area of the electrode, d is the thickness, and ϵ is the dielectric constant of the clothes. For a high coupling capacitance, large contact areas of electrode surface within small distances from the body are essential.

The second methodology is to reduce noises contaminated in signals. One of the effective ways is the use of a driven right leg (DRL) in which the common mode (CM) signal from the two sensors is capacitively coupled onto the driver's body inversely. This technique also provides cancellation for noise introduced by driver's movement artifacts. Another noise rejection is achieved by differential amplification and filtering after the signals are digitized. The differential amplification of the combined electrode signals provides amplification and reduces the CM noise.

In this study, cECG monitoring system is implemented with consideration of these two methodologies. Then the system is evaluated with 5 subjects in situations of engine on and off with an actual car.

3. Implementation

Figure 1 shows the configuration of the cECG monitoring system developed with the considerations of two methodologies mentioned above. Flexible electrode and neutralization circuit was designed mainly for signal attenuation avoidance, and AC coupling circuit, DRL, and digital filtering by DSP are made for noise suppression.

3.1 Flexible active electrode

Capacitive electrodes are especially difficult to employ compared to gel-based counterparts due to the high capacitive source impedance. Small effective area of electrode sensing surface and low signal frequencies (10–30 Hz) result in extremely high source impedances. Therefore, even small variations in the coupling capacitance and distance between channels can lead to large amounts of distortions due to signal attenuation and the mismatches of channels. This can be somewhat mitigated since large effective electrode surfaces are permissible. It is important to consider the size and curvature of the electrode. Because the surface of the human torso is curved, air gaps were created between the capacitive electrode face and the subject's back, resulting in poor contact and a low signal noise ratio (SNR) signal, which deteriorates signal quality. To acquire flexibility and large electrode surface is a key to improve the cECG measurement. In this study, polyimide was used to realize these features. The electrode is consisted with four layers of copper plates and two layers of 50 μm thick polyimide plates Fig. 2(b). Prepreg, 70 μm thick, is sanded with 17 μm thick copper plates, and is covered with the polyimide plates. Copper plates, 35 μm thick, are placed exterior of the polyimide plates, and one side is used for a circuit layer of the component, and the other side is for electrode face. Both outer sides of the layer are covered with 50 μm thick insulation layer of the electrode. The total thickness of the electrode is about 370 μm; therefore, it can be easily bended as shown in the Fig. 2(a) and fits to the curvature of