Integrated circuit measurement of skin conductance

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An active skin-conductance measuring device, utilizing integrated circuit operational amplifiers, is described. The transducer offers accurate measurement despite fluctuations in source voltage. The circuit also provides protection in case of accidental short circuit.

Lykken and Venables (1971) and Venables and Christie (1973) have recently provided excellent reviews of the characteristics, mechanisms, and measurement of electrodermal activity. In response to the variability of measurement techniques utilized in the expansive electrodermal literature, they have advocated the direct measurement of skin conductance (SC) as a standardized practice. The relationship of conductance to the underlying physiology of the skin indicates a need for measuring SC, rather than measuring skin resistance as was characteristic of earlier practices.

While the circuit proposed by Lykken and Venables (1971) has been demonstrated to provide satisfactory performance, this report offers an equally inexpensive and more sophisticated skin-conductance measuring device that utilizes readily available integrated circuitry. The transducer is used in conjunction with the Grass Model 7P1 low-level dc preamplifier; however, it is compatible with most commercially available dc preamplifiers.

DESCRIPTION OF CIRCUIT

The versatile properties of the inexpensive $\mu 741$ operational amplifier (op amp) make it an ideal basic element in the construction of low-frequency biomedical measuring circuits (Swinnen, 1968). In the configuration shown in Figure 1, the op amp functions as an amplifier, with the gain determined by the input and feedback resistances. If the input resistance is the skin resistance, the output voltage will be inversely proportional to this resistance or directly proportional to the input conductance.

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Figure 1. Basic circuit for conductance measurement.

Figure 2. Operational amplifier as a difference amplifier.

In Figure 2, the output voltage is equal to the difference between the input voltages. If one input voltage (V_A) parallels skin conductance, and the other (V_B) is proportional to a known conductance level, this circuit provides a means of suppressing a desired amount of tonic SC level (SCL).

Figure 3 depicts the complete SC measuring circuit. IC1 and IC2 both operate in the mode of Figure 1, while IC4 operates in the mode of Figure 2. IC2 measures the conductance applied to the input jack. The output of IC2 is a voltage from 0 to 1 V for a range of conductance from 0 to 100 μmhos . The conductance may be increased to 900 μmhos with the 9-V supply before IC2 saturates. As the gain of the circuit goes up (as conductance increases), accuracy decreases. At a conductance of 666 μmhos ,

Figure 3. Circuit diagram for op amp SC measuring device. Each IC has a nulling potentiometer connected in the conventional way for the nulling of the offset voltage at the output pin (Pin 6). The nulling pots, designated P1 to P4, respectively, are not shown in this circuit.

the accuracy is still within 1%. The range of interest for the present circuit will be 0-100 μmhos .

IC3 is connected to perform the same function as IC2, except that the input conductance consists of known levels of 10 μmhos , 20 μmhos , and a variable conductance source of from 2 to 100 μmhos . In order to have this variable suppression calibrated, a 10-turn calibrated potentiometer can be used in place of the 500-k Ω pot. This 10-turn pot is so arranged that the dial readings on the pot translate directly into micromhos. Thus, when one adjusts this dial to properly position the pen on the chart, and then notes the reading, the latter value indicates the number of micromhos which have been subtracted from the subject's total SCL. In this manner, one can, at any point, get an exact reading of SCL while using a sensitivity high enough to register the smallest SCR.

A circuit similar to Figure 2 is used on IC4 to allow the suppression of the SCL derived from IC3. The signal at V_A is compared with the signal at V_B , and the output represents the difference. A switch is provided to change the gain of IC4 from unity to 10 to provide a 10-fold increase in sensitivity of the circuit. The accuracy of the output signal is less with increased sensitivity.

On the output of IC4 is a voltage divider to make the circuit compatible with the input characteristics of the Grass Model 7P1 low-level dc pre-amplifier. The midsetting of 1 mV/cm on the preamp is used to produce a final printed response of 1 $\mu\text{mho/cm}$. The voltage divider makes the output 1 mV/ μmho , or 10 mV/ μmho , depending on the $\times 1$ or $\times 10$ selection on the sensitivity switch.

IC1 is used as a buffer amplifier to produce a precise regulated voltage to be applied to the skin segment. A 5-V Zener diode is connected through a 330- Ω resistor from V^- to ground. The voltage across this Zener is constant at approximately -5 V for a wide range of V^- . The 10K trim pot serves as a fine adjustment of this voltage.

IC1 is a 1/10 gain amplifier that produces a regulated voltage of +500 mV at the input jack.

The power supply for this circuit consists of two batteries which may range from 7.5 V to 18 V and still maintain the output at 100 mV $\pm$ 1%. All resistors used in the circuit are of the 5% $\frac{1}{4}$ -W type. The value of the feedback and calibration resistors are known to within 1%, as determined on a laboratory bridge circuit. The capacitors in the feedback paths of IC2, IC3, and IC4 are for the suppression of high-frequency transients.

CIRCUIT PERFORMANCE

A plot of the output voltage against the input conductance produced a linear relationship over the desired range, with negligible error. The maximum output of the circuit was found to be 700 μmhos on the $\times 1$ scale.

The current drawn from the supply was measured at each supply terminal. From V^+ , the current was 4.6 mA, and from V^- it was 9.40 mA. The dependence of the circuit on the supply voltage was recorded. In Table 1, the output voltage is recorded for supply voltages at the lower end of possible values for both of the sensitivity scales and both ends of the conductance range.

PRINCIPLES OF OPERATION

Operating Instructions

The following operating instructions apply to the Grass polygraph and Grass 7P1 low-level dc pre-

Table 1
Output Voltage as Function of Supply Voltage and Sensitivity

Sen- sitivity	Conductance (mhos)	Voltage		
		9 V	8 V	7.5 V
$\times 10$	2	20 mV	20 mV	21 mV
$\times 1$	200	200.7 mV	200.1 mV	199.4 mV

amplifier; however, adjustments are similar on other commercial polygraphs: (1) Calibrate the Driver Amplifier as usual. Set the $\frac{1}{2}$ -A high-frequency filter to "3" in order to filter out 60-Hz noise. (2) Initial control settings are made as follows (refer to Figure 4): Set S1 (Power) to OFF; Set S2 (Gain) to $\times 1$; Set S3 (Baseline) equal to zero; Set S4 (Calibrate) to OFF; Set P1 (Variable) = presently inactive. (3) Input S to J1, using standard bipolar electrode placement. (4) Output, at J2 (1 mV/ μ mho), plugs into the dc preamplifier. (5) Calibration: Turn Power, S1, to ON. Then set Calibrate, S4, to ON. With Baseline Select, S3, set at zero, the polygraph pen should be in the center of the chart paper. If a baseline position other than the center of the chart is desired, reposition the pen using the Baseline Position control on the Driver Amplifier. Set S3 on 10 μ mhos. This inputs a "dummy" 10 μ mhos for calibration. Adjust sensitivity (Cal control) on the dc preamplifier for 1 cm of pen deflection. With this setting, 1 cm of pen deflection is equal to 10 μ mhos and 1 mm is equal to 1 μ mho. To further check calibration, set S3 on 20 μ mhos. The pen should deflect 2 cm if adjusted properly. (6) To establish the subject's baseline value, set S3 on zero and S4 to "OFF." The polygraph pen will deflect upward. The number of millimeters of upward deflection from the baseline position equals the subject's baseline SC level in micromhos. Record this value on the chart paper. (7) To record, set S3 to "VARIABLE." Then adjust Variable potentiometer, P1, until the polygraph pen is returned to the preselected baseline position. The baseline position is now equal to the subject's tonic (baseline) SC level, and any pen deflections from this position are read as deviations from baseline SC level.

Occasionally the sensitivity of the recording procedures must be altered in order to accommodate variability in SC responses. In these circumstances, simply increase or decrease the gain by stepping the sensitivity switch on the dc preamplifier from 1 mV/cm to either .5 mV/cm or 2 mV/cm, with no adjustments needed on the transducer. For example, should one encounter a subject whose SC response

Figure 4. Skin-conductance transducer.

Figure 5. Circuit board with cover off (top view). All resistors are $\frac{1}{4}$ W 5%; value of feedback, baseline, and calibration resistors are known to 1%. IC2, IC3, IC4 have 10K offset nulling pots (not shown).

is undetectable following the aforementioned procedures, then the sensitivity switch on the dc preamplifier should be stepped up to .5 mV/cm. In this instance, 1 cm of pen deflection would now equal .5 μ mhos of SC, doubling the sensitivity.

Calibrating Instructions

It is not necessary to calibrate with every use. Calibration may be necessary if battery weakening is suspected, or when the baseline 10- μ mho or 20- μ mho switch appears to be delivering an inaccurate output with S4 in the "CALIBRATE" position.

To calibrate: remove the outer case and turn the power on at S1. Then check the battery voltage. If the voltage is near 7.5 V, replace the battery. Then, in sequence, remove the input, set the BASELINE (S3) at zero, set the GAIN (S2) at $\times 10$, and set CALIBRATE at "OFF." Then, referring to Figure 5, adjust Pot 1 (P1) to output 500 mV [with respect to ground (chassis)] at Pin 6 of IC1. Adjust Pot 2 (P2) to give minimum voltage [with respect to ground (chassis)] at Pin 6 of IC2. Adjust Pot 3 (P3) to give minimum voltage [with respect to ground (chassis)] at Pin 6 of IC3. Adjust Pot 4 (P4) to provide minimum voltage [with respect to ground (chassis)] at Pin 6 of IC4. Then set S4 to "CALIBRATE" and BASELINE to 10 mhos; the output voltage should be 100mV $\pm$ 1%.

DISCUSSION

The skin-conductance transducer described in this paper is somewhat superior to the passive circuit described by Lykken and Venables (1971). Although the Lykken and Venables circuit uses expensive mercury cells, and the output voltage of the device is directly proportional to the voltage of these cells, the active circuit presented here is, as indicated by Table 1, extremely insensitive to variations in

supply voltage. The Lykken and Venables circuit also requires 1% resistors; the active circuit requires only 5% resistors. The active circuit has also been designed to protect the measuring op amp in case of an accidental short circuit at the input terminal.

One interesting modification is to connect a zero center meter to the output jack (J2) or through the output of the Driver Amplifier for the purposes of providing visual feedback for biofeedback applications. The SC measuring device has provided extremely reliable performance over numerous recording hours.

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