FOREWORD

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ABSTRACT

The problem of monitoring galvanic skin resistance, especially when used in combination with electrocardiographic or electroencephalographic recordings, is discussed. A new approach is outlined that eliminates interference from other measurements. A small, lightweight laboratory model has been built that has low power consumption and is insensitive to vibration and acceleration forces. The performance, stability, and accuracy of the model is equivalent to larger, more conventional instruments used for the same purpose.

PUBLICATION REVIEW

This technical documentary report has been reviewed and is approved.

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A SOLID STATE MEASURING DEVICE FOR GALVANIC SKIN RESPONSE

INTRODUCTION

Galvanic skin response (GSR) is used in many research projects concerned with psychophysiological effects. Literature about the GSR phenomena, as well as its application to different research problems, is quite extensive. Comparably, fewer investigations have been made from the instrumentation aspect of the subject. This report discusses the problems that may be encountered in working with the available instruments and describes a new approach having several important advantages for practical use, especially if combined with multiple measurements on the same subject. The instrument developed is based on a completely solid state design principal. It is small, light-weight, and has low power consumption; however, the accuracy and stability is comparable to larger, more conventional instruments used for the same measurements.

PROBLEM AREAS IN MONITORING GALVANIC SKIN RESISTANCE

Skin resistance and its variations with external and internal stimuli can be measured with either alternating current or direct current. A third method, which also reflects skin reactions, measures potentials produced by the skin itself. This investigation is restricted to skin resistance measurements with direct current exclusively. The resistance of the human skin, often called the apparent resistance (because of polarization effects), varies from a few thousand to several million ohms, depending on area and composition of electrodes and electrolyte, current density, condition of the subject, temperature, humidity, and air pressure. This resistance is calculated from current and voltage and is called the base resistance.

Physiological or psychological stimuli cause small variations (in the order of a few percent) of this resistance, which are referred to as specific response. A resting subject with no stimuli applied produces even smaller changes, which are presumably caused by internal stimulation from the subject himself, called nonspecific responses. Discrimination between specific and nonspecific responses is often very difficult if not impossible. In many experiments, the skin responses that can be related to a stimulus (intended or not) are called specific while the remaining responses are considered nonspecific. Specific and nonspecific responses have a particular pattern that can be used to distinguish them from random fluctuations or artifacts. The measuring devices used are based on constant-voltage systems (ohmeter) or constant-current methods. In a certain range of current density on the electrodes (up to 10 $\mu A/CM^2$), the skin resistance and the specific or nonspecific responses expressed in resistance changes are independent of current (ref. 2). In this range of current density, preferred by most investigators, constant-current methods give the same result as the constant-voltage system. To measure the small changes of the specific or nonspecific responses three different systems are in use. The simplest one employs a capacitive-coupled amplifier with sufficient time constant to reproduce the skin response (approximately 5 seconds). In the absence of a response the output drifts to the centerline. Changes in base resistances are in most cases slower and, therefore, are not passing the amplifier. However, this system is limited to experiments with comparable slow changes in base resistance. Another approach uses a self-balancing bridge circuit where electromechanical step switches balance the resistance bridge automatically. A medium gain d-c amplifier allows the specific and nonspecific responses to be read. The third method uses a memory capacitor. The resistance is converted into a proportional voltage that is stored in the capacitor. If this voltage exceeds a preset amount, a relay connects the capacitor to zero voltage, resetting the output of the amplifier to the centerline.

Both machines are power-line operated and require grounding, not only for safety, but also to prevent a-c interference if used simultaneously with other measurements like electrocardiograms or electroencephalograms. This requirement, in turn, makes it necessary to use amplifiers with extremely high common-mode rejection for the other measurements to prevent artifacts caused by changes in skin resistance.

Since the common-mode rejection is not only a property of an amplifier, itself, but also is affected by unequal pickup electrode impedance, special care in electrode application is necessary. The machines with electromechanical switches produce clicking noises that often interfere with the particular experiment. Therefore, the equipment must be operated in a special room separated from the subject. The high-sensitivity relay in the capacitor-type machines is also sensitive to vibration and acceleration forces. Using this machine in aircraft or vehicles is therefore limited to certain vibration and acceleration levels.

GSR DEVICE OPERATING PRINCIPLE

Three main objectives have guided this design. First, the circuit including the subject should have no galvanic connection with other parts of the equipment. Second, mechanical switches and relays should be avoided to allow the GSR device to be used in aircraft and vehicles. Finally, minimum power consumption, weight, and size are desired. Figure 1 shows a transistor oscillator that works on a frequency between 20 and 100 kilocycles, the secondary of TR being connected to a full-wave rectifier. The d-c voltage produced is applied to the electrodes attached to the subject. The voltage on the primary of TR is rectified with a voltage doubler that produces a d-c voltage on point B. If the resistance between the electrodes changes, different loadings of the oscillator cause a change in voltage on point A and, in turn, on point B. The d-c voltage on point B is also a function of the resistance between the electrodes. Figure 2 shows the relation of the resistance between e_1, e_2, and the d-c voltage on point B. Using frequencies between 20 and 100 kilocycles allows a physically small transformer, TR, with a low capacity between primary and secondary to be used. The circuit, including the subject does not have a galvanic connection, and its capacitive coupling is very small so no common ground-loop problems occur if the system is used with EKG or other measurements. Another advantage of this approach is its inherent safety. There is no condition possible where the voltage on the electrode may exceed a preset level of approximately 8 volts. In constant current systems, a break in the electrode circuit causes the voltage to increase to 100 or 200 volts, which may cause a shock or discomfort to the subject under certain conditions (intermittent contact, small electrode area, dry electrodes, etc).

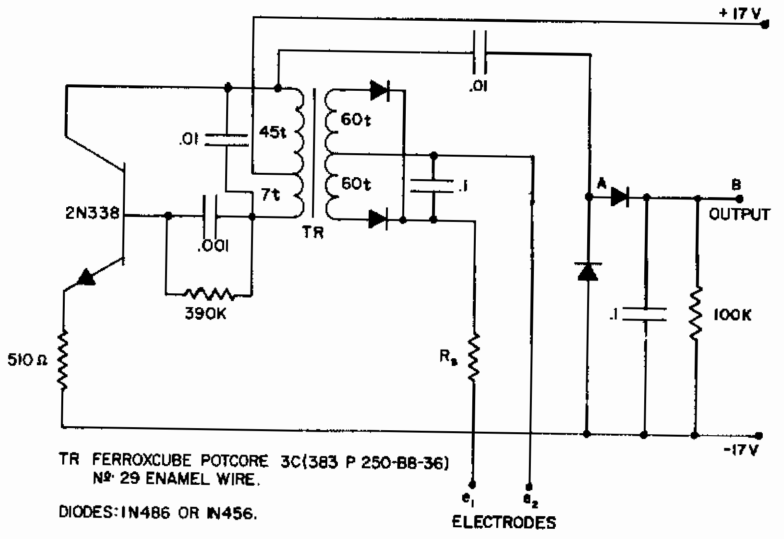


Figure 1.

Input Signal Conditioner A

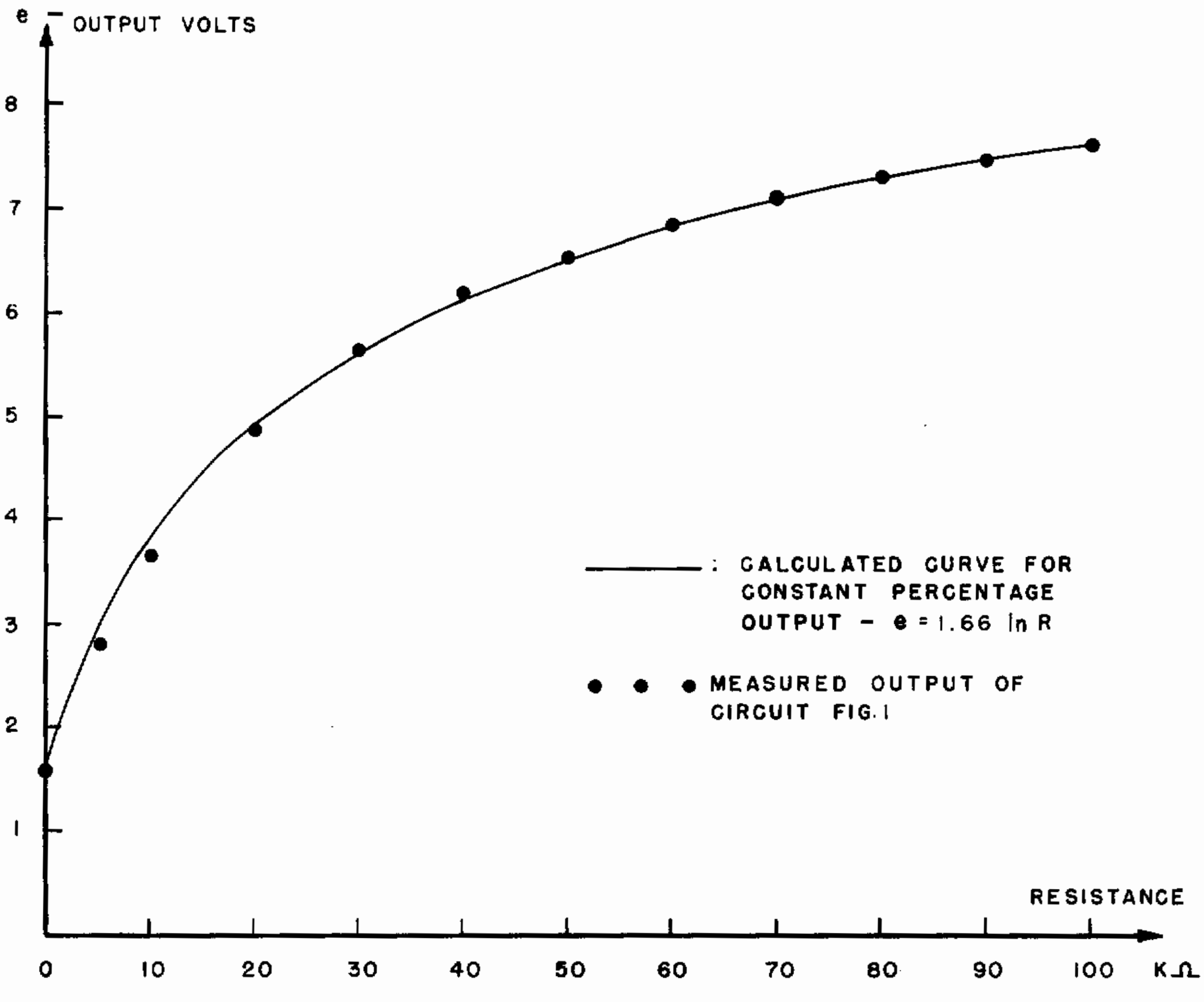
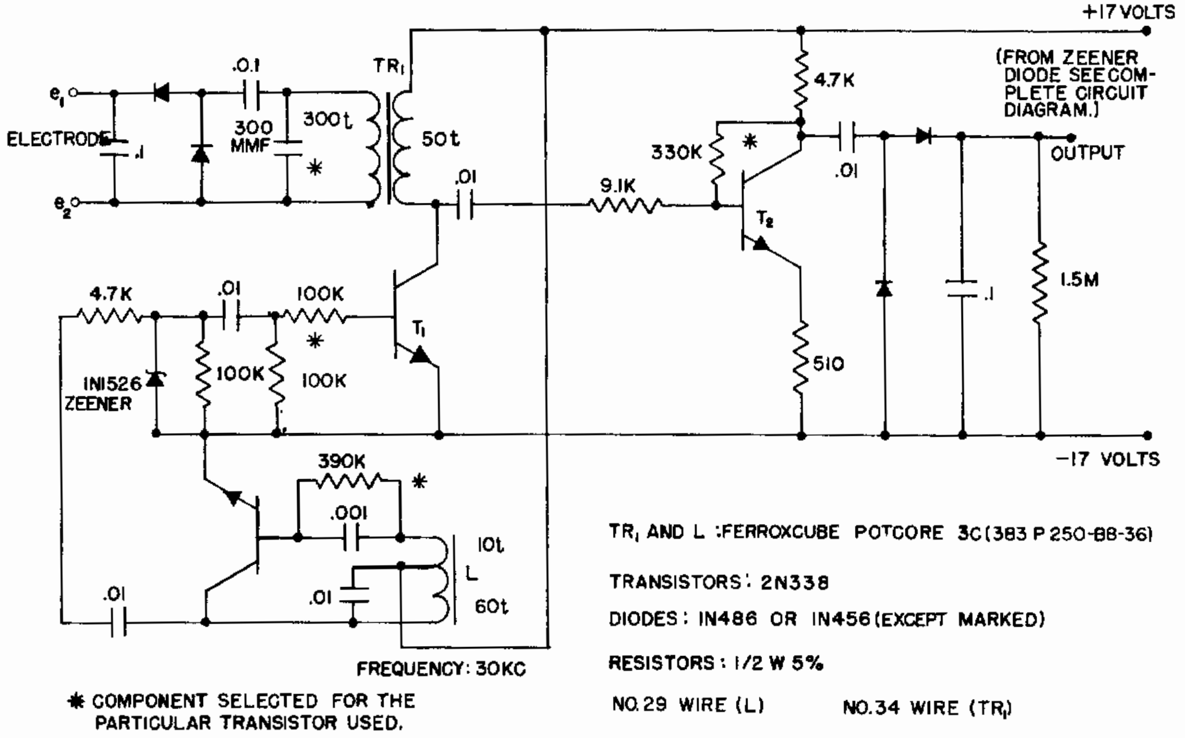


Figure 2. Transfer Characteristic of Input Signal Conditioner A

The voltage on point B represents base resistance and may be recorded directly or after amplification. Adding a capacitive-coupled amplifier gives readout of specific or nonspecific responses in the simplest way. This simplified combination has only limited application in experiments where slow changes in base resistance are anticipated. Fast base resistance changes and artifacts may cause blocking of the amplifier for several seconds resulting in loss of information. On the other hand, the simplicity makes this circuit suitable for use in personal telemetry systems where size and number of components are the most important considerations.

According to the diagram, figure 2, the output voltage is not a linear function of the resistance, but approaches a logarithmic function similar to the reading of an ohmeter. For small resistance deviations, however, the curve may be considered linear with an error of a few percent. The fine resistance (specific) reading, therefore, shows the actual shape, but its amplitude is not representative of the same resistance change for different base resistances. With increasing base resistance the fine resistance reading represents a higher actual resistance change. The quotient $\frac{\text{fine resistance}}{\text{base resistance}}$ remains approximately constant for a useful range of base resistance (see appendix).

The evaluation of GSR recordings is not yet standardized. One method of evaluation is to calculate the quotient and express the result in percent. For this method the previously described circuit simplifies the evaluation, because the output for fine resistance has already given this quotient and may be calibrated in percent. Another method requires the absolute resistance change in ohms independent of base resistance. For this method the approach outlined is not practical because it would require too many calculations. A different input signal conditioner has been developed. Figure 3 shows the circuit diagram. Transformer, TR_1, is supplied with a constant current because of transistor, T_1, which is fed with constant voltage produced by the oscillator and the Zener-diode clipper. A resistive load on terminals e_1 and e_2 (skin resistance) is reflected into the secondary winding of transformer, TR_1, causing a voltage drop which is proportional to the loading resistance on e_1 and e_2. This voltage drop is amplified with transistor, T_2, and rectified with a diode-voltage doubler.



✱ COMPONENT SELECTED FOR THE PARTICULAR TRANSISTOR USED.

TR_1 AND L :FERROXCUBE POTCORE 3C (383 P 250-88-36)

TRANSISTORS: 2N338

DIODES: IN486 OR IN456 (EXCEPT MARKED)

RESISTORS: 1/2 W 5%

NO.29 WIRE (L) NO.34 WIRE (TR_1)

Figure 3. Input Signal Conditioner B

In order to achieve linearity between resistance and output voltages, the transformer, TR_1, must have low losses, low leakage inductance, and sufficiently high impedance for the frequency used (30 kc).

A capacitor, C_3 (300 mmf), is employed to tune the transformer to the oscillator frequency, therefore, a smaller transformer with sufficient impedance can be used. Sufficiently high voltage to work in the linear part of the silicon rectifier characteristic is also important. Figure 4 shows the relation between resistance on terminals e_1, e_2, and output voltage.

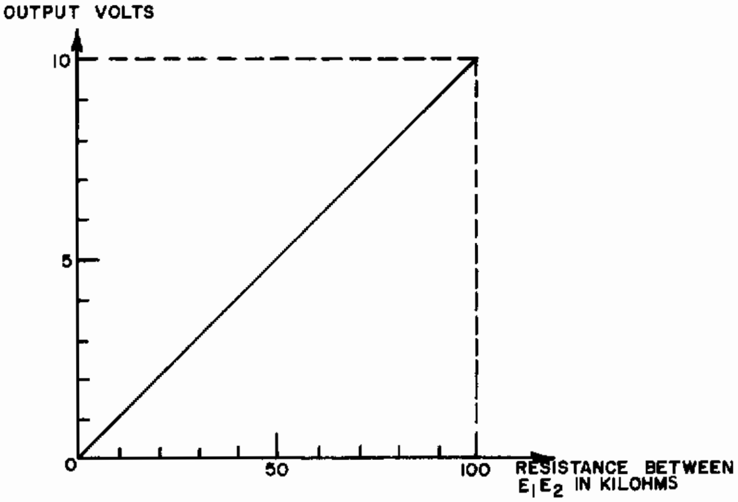


Figure 4. Transfer Characteristic for Input Signal Conditioner B

GSR WITH AUTOMATIC RESET

Figure 5 shows a block diagram for the complete unit with automatic electronic reset of the fine resistance output. The block input-signal conditioner represents the same circuit shown in figure 1 and figure 3. In case the output of the fine resistance terminals exceeds a preset fine resistance range, Schmitt trigger ST-1 or Schmitt trigger ST-2 will be activated, if the voltage reaches the high or low limit. Each Schmitt trigger activates the electronic switch which discharges capacitor C. The sudden voltage drop on the input of the amplifier resets the output voltage to the center value and resets the Schmitt triggers ST-1 or ST-2. Since this resetting process requires only about 3 milliseconds, the system is able to respond immediately to another specific response.

Figure 6 represents the complete circuit diagram. After the previously described input signal conditioner, an emitter follower stage with a sensitivity selector switch provides low impedance and sensitivity control. Following the capacitor, C, a transistor chopper amplifier is employed to achieve stable d-c amplification and sufficient high input impedance. Schmitt trigger, ST-1, responds if the output of the amplifier exceeds a low limit while Schmitt trigger, ST-2, senses the upper limit. These limits are set with the potentiometers, P_2 and P_3. The Schmitt triggers activate the electronic switch which consists of an oscillator and the two switching transistors, TS_1 and TS . The two transistors (bi-directional switch) connect the capacitor, C, to a voltage divider that is set to give reset to the centerline of the output.

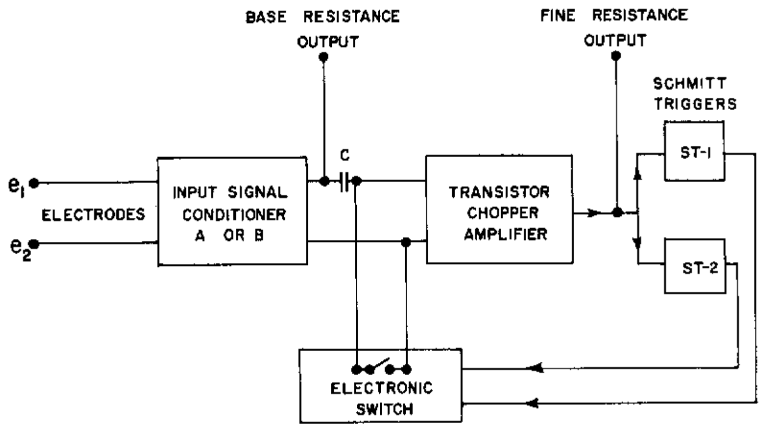


Figure 5. Block Diagram for Complete GSR Device

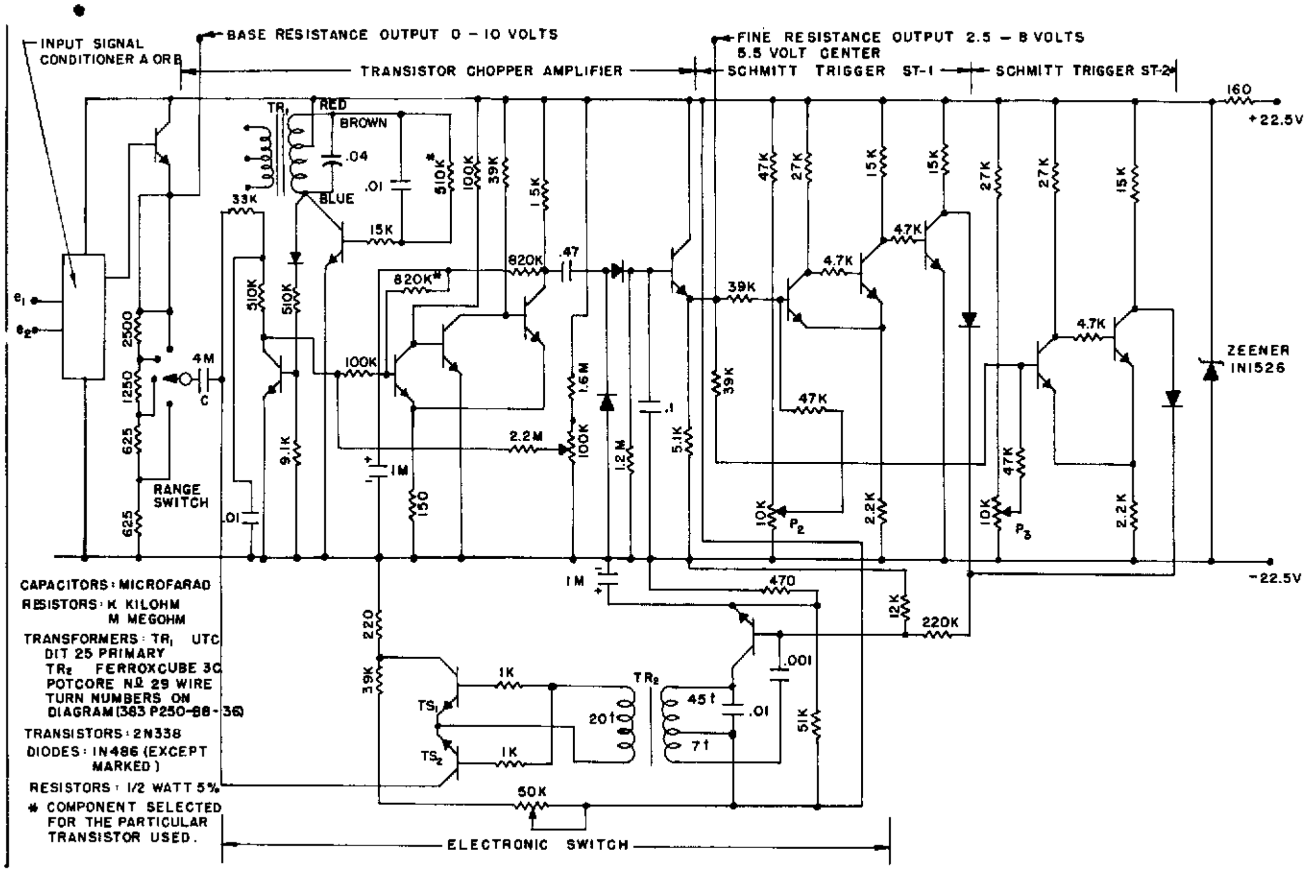


Figure 6. Circuit Diagram for GSR Device

The output for base resistance varies from zero to 10 volts in accordance with 0 to 100 kilohm resistance. The fine resistance output has a center voltage of 5.5 volts and may vary between 3 and 8 volts. (Reset to center occurs if the voltage drops below 3 volts or exceeds 8 volts.) The outputs may be fed into a standard recording or telemetry system or used to drive a meter (100 uA). For some recording systems, a compensating voltage for the fine resistance output is necessary to bring the center voltage from 5.5 volts to a lower value.

The range-selector switch controls the sensitivity for the fine resistance. Highest sensitivity is 500 ohms for an output of 2.5 volts (maximum). Steps for 1000, 2000, and 4000 ohms are provided in the laboratory model.

There are many different kinds of electrodes in use which have different ranges of skin resistance. This model was built for electrodes with base resistance between approximately 2 and 100 kilohms. Adapting the apparatus for higher or lower resistance values requires only changing the number of turns on the secondary of transformer, TR_1 (see appendix). For universal use with any electrode, the secondary should have several taps and a selector switch. Calibration of the unit may be established by connecting a precision resistance box to the input and recording a number of resistance steps.

Figure 7 shows a recording on a two-channel Brush recorder. The upper trace has been made from the left hand of the subject with a conventional GSR machine (memory-capacitor type). The lower trace is the output from the unit described above, taken from the right hand of the same subject.

Figure 8 is a photograph of the laboratory model of the GSR device.

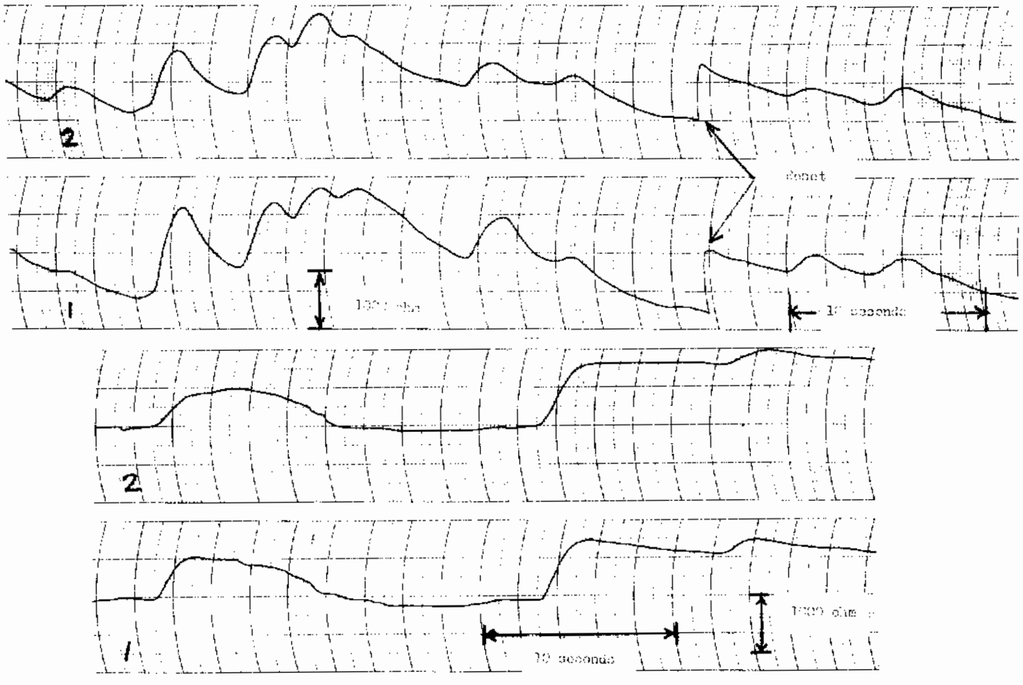


Figure 7. Simultaneous Recordings on Same Subject

Trace 1 - New solid state apparatus, right of subject
Trace 2 - Conventional GSR apparatus, left hand of subject

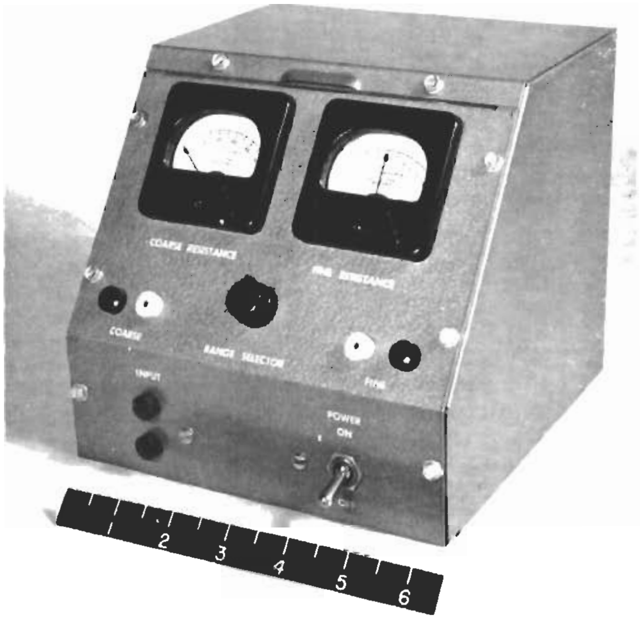


Figure 8. Laboratory Model of GSR Measuring Device

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APPENDIX

BASE RESISTANCE QUOTIENT

The fine resistance output of signal conditioner, A, is proportional to the slope of the transfer characteristics on the point of the particular base resistance. In an ideal case this slope or the differential quotient $\frac{de}{dR}$ (e = output voltage, R = base resistance) should be an inverse function of the base resistance, R. The equation $\frac{de}{dR} = K\frac{1}{R}$ must be satisfied in order to achieve a fine resistance output that is a percentage of the base resistance. Since the function, $e = K \ln R$, has the first derivative, $\frac{de}{dR} = K\frac{1}{R}$ this function meets the requirement accurately. In figure 2 the calculated function, $e = 1.66 \ln R$, is shown as a solid line. The circles represent the measured output voltages versus base resistance, R. The diagram indicates a very close relation between the ideal calculated curve and the measured results in a wide base resistance range. The shape of the transfer characteristics is dependent on the series resistor, R_S, in the subject circuit. (See figure 1.) Adjusting this resistor for a particular input signal conditioner allows the transfer characteristics to be matched to the theoretical shape.

The model described was built for a base resistance range from 2 to 100 kΩ. If a higher or lower resistance range is desired, the secondary of the transformer (in the subject circuit) should have a different number of turns for best results. The transformer equation, impedance impedance = $K.\,n^2$, may be used with a factor, K, calculated from this transformer. For a center impedance of $50,000 = Kn^2 = K.\,120^2$ $K = 3.47$. Number of turns on secondary, n, for a desired center impedance R is $n = \sqrt{\frac{R}{K}}$.