A system for cutaneous electrical stimulation mimicking touch*

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An electrical system is described which produces pain-free touch sensations similar to those from mechanical stimulation. The apparatus is inexpensive, easily constructed, and can be used with human or animal Ss.

In the study of touch and vibration, the most common technique has been mechanical stimulation of the skin. The basic device consists of a plunger, which is repeatedly lowered to indent the skin. Such mechanostimulators have several disadvantages: they are bulky and are difficult to attach firmly to awake, manipulative Ss, such as monkeys. Furthermore, the onset and offset times of stimulation are relatively slow, being governed by the mechanical properties both of the device and of the skin. Thus, interest has arisen in systems of electrocutaneous stimulation, which would mimic mechanical stimulation while lacking its disadvantages.

The optimum electrical stimulus for pain-free touch has been established as an anodal dc constant-current square-wave pulse of 0.5-msec duration and 1-3-mA intensity (Gibson, 1968). These stimulus parameters can be obtained from commercially available equipment, but the range of operating parameters is often unnecessarily wide for much behavioral research, and the relatively high cost of such equipment can be a deterrent. We therefore present an inexpensive device, easily constructed with readily available components and compatible with widely used programming equipment, for electrocutaneous stimulation which mimics touch.

The system is outlined in Fig. 1. The constant-current stimulator is triggered by the output of a BRS Digi-Bit One Shot, whose pulse width is set at 0.5 msec. Each pulse rises from −6 to 0 V in 1 microsec. Associated BRS programming modules control pulse repetition rate and train duration.

The constant-current stimulator circuit illustrated in Fig. 2 performs as a gated constant-current generator for varying load impedances. The gating action is controlled by Q1 and its associated circuitry, while the adjustable constant-current generator consists of Q2 and components associated with it. The circuit operates as follows: The 47K resistor and the three 1N456 diodes are used to develop a +2.1-V bias level for Q1. When the input signal is at 0 V, the base of Q1 is at +0.7 V and Q1 is biased on, this in turn biases Q2 on, and a constant current appears across the output terminals. When the input is more negative than −4 V, Q1 will turn off and hence turn off the constant-current generator.

Q1 is therefore acting as an electronically controlled switch, and grounds the 6.2K resistor when it is turned on. When this resistor is grounded, 6.7 V is developed across the series combination of the Zener diode and the signal diode. The 0.7-V drop across the signal diode approximately compensates the base-to-emitter drop across Q2, producing a 6-V potential across the emitter resistors. Q2 operates as a constant-current source, and the current flowing through the collector circuit is almost equal to the current flowing through the emitter circuit. Thus, by adjusting the variable 10K emitter resistor, the current source is made adjustable and the output current is closely approximated by $I_{output}(MA) = [6\ V/R_{emitter}(K)]$. The range of output current is therefore 0.55-6 mA.

The 10K resistor between the base of Q2 and the power supply is provided to reduce stray leakage current when the unit is gated off, and the 1M resistor from collector to ground prevents the leakage current present from producing an appreciable charge across stray capacitance when no load impedance is connected to the unit.

All the current flowing through the load also flows through the 1K current monitor resistor, and if an oscilloscope is connected between the monitor terminal and ground, a potential of 1 V will be observed for every milliampere flowing through the load. The load impedance should not have an auxiliary return path to ground, as this would produce erroneous readings through the monitor circuit.

The unit is insensitive to power supply variations and will work with lower supply voltages. If higher voltages are to be used, it would be necessary to use transistors with a higher breakdown voltage capacity. The choice of supply voltage limits the maximum current for different load impedances. Since for proper operation 11 V should be allowed between the power supply and the collector of Q2, the current limitation as a function of supply and load impedance is approximated by:

$$I_{load\ (max)} = \frac{V_{supply} - 11\ V}{(R_{load} + 1K)}$$

The anodal output of the stimulator goes to the stimulating electrode assembly, which is constructed as follows: A Dr. Scholl's No. 313 callous pad, a cushioned ring with an inside diameter of 5/8 in. and an adhesive back, is placed on the shaved skin. The center of the ring is filled with electrode paste, and a Beckman electrode collar is laid on top of the ring. The copper-disk stimulating electrode, 7/8 in. in diam, is placed on

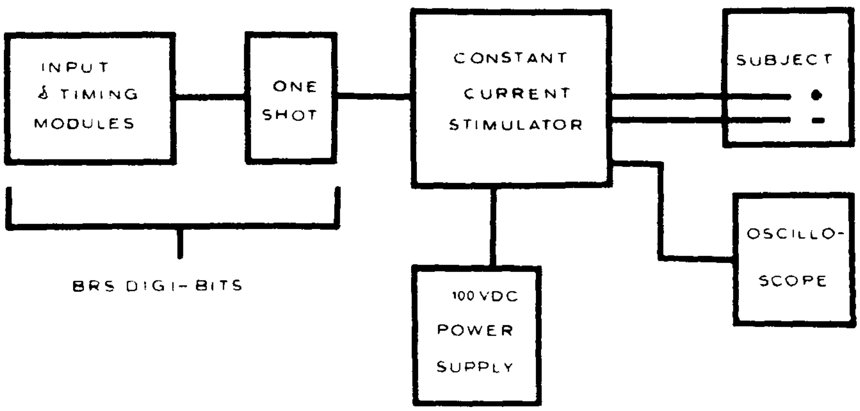

Fig. 1. Block diagram of the stimulating system.

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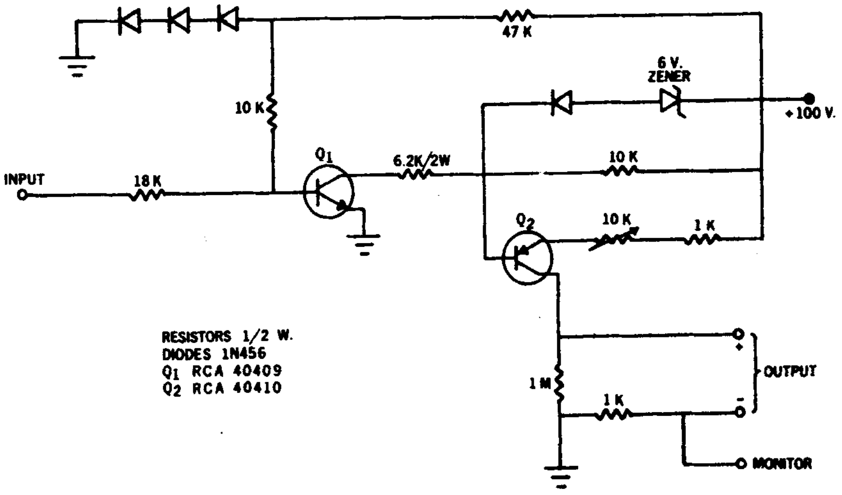

Fig. 2. Circuit diagram of the constant-current stimulator.

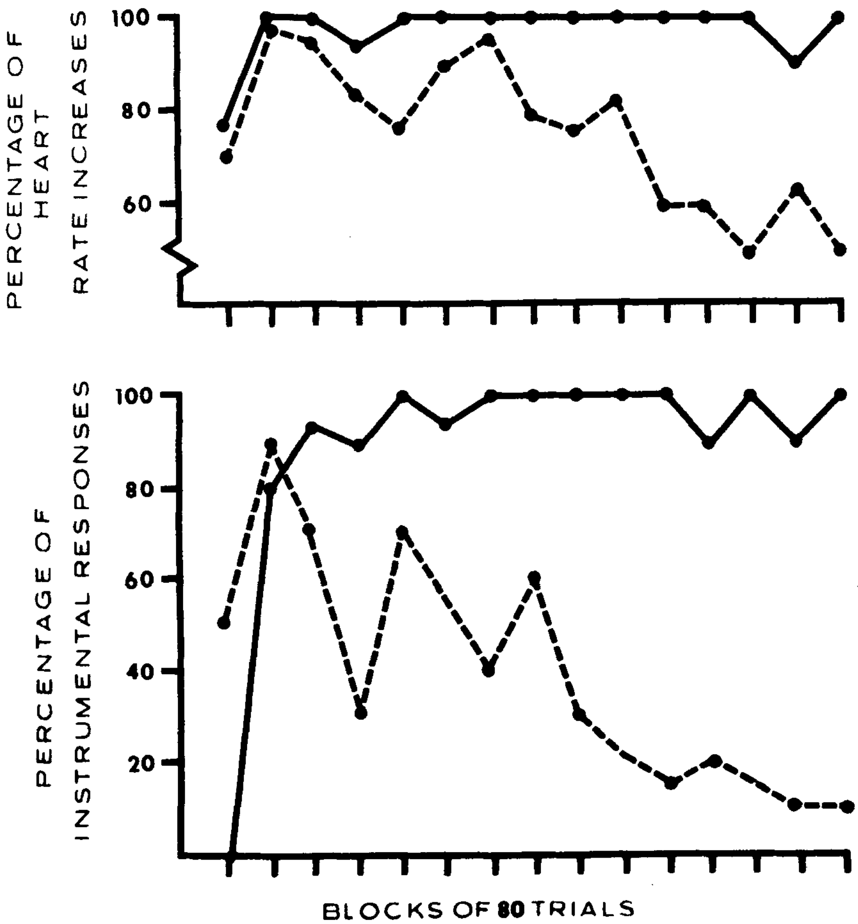

Fig. 3. Percentage of conditioned heart-rate increases (upper graph) and instrumental avoidance responses (lower graph) to cutaneous electrical stimulation at two locations on the arm. Stimulation of one location (solid line) was terminated by aversive reinforcement unless an instrumental response was made, whereas stimulation of the other location (dashed line) was not followed by reinforcement.

top of the collar, contacting the paste. With cooperative Ss, this assembly will stay in place; with monkeys, it is necessary to wrap a small Ace bandage section around the arm, covering the assembly, in order to secure it.

The other output goes to a 3 x 2 in. curved copper ground electrode, moistened with electrode paste, which is attached to the leg with an Ace bandage in a similar fashion. This electrode must be considerably larger than the stimulating electrode.

By appropriate switches between the stimulator and the S, the output can be directed to one of any number of stimulating electrodes.

The cost of this system is reasonable. If the BRS equipment is not already available, a package which will deliver a timed train of pulses, initiated and terminated by the E, costs $240. This includes a −12-V dc power supply and one each of input unit, flip-flop, multivibrator, and one shot, as well as associated hardware. The constant-current stimulator can be built for $36; the most expensive item is the 10K adjustable resistor (Clairostat 62JA). As explained in the circuit description, there is considerable latitude in the choice of power supply for the stimulator. We have used a Sorensen Q Nobatron Model QR75-2 because it was available; an adequate 100-V dc power source can be built for approximately $60.

To human Ss, this electrocutaneous stimulation at 3 mA feels like a light tap on the skin, as from the eraser end of a pencil. The sensation is felt under the anodal electrode; there is no sensation from the ground electrode.

We are confident that such stimuli mimic pain-free touch for the monkey as well. We have taught eight rhesus monkeys to discriminate between cutaneous stimulation at two locations, upper and lower arm. Each conditioned stimulus consists of a train of 10 pulses, separated by 2.5 sec. Stimulation at one location is followed by aversive electric shock unless the S performs an instrumental response; at the other location, stimulation has no consequences. We observe conditioned heart-rate responses and instrumental responses throughout training. Ss show conditioned heart-rate increases and instrumental responses after a short period of training, indicating response to the cutaneous stimulation. Furthermore, the frequency of autonomic and instrumental responses to the nonreinforced stimulus gradually decreases, indicating that the cutaneous stimulation is not painful and that a discrimination based on the location of stimulation on the body surface can be established. Data from a representative animal are shown in Fig. 3.

REFERENCE

GIBSON, R. H. Electrical stimulation of pain and touch. In D. R. Kenshalo (Ed.), *The skin senses.* Springfield, Ill: Thomas, 1968. Pp. 223-261.