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BRIEF COMMUNICATION

A Device for Wireless Electric Brain Stimulation in Operant Conditioning Situations[1]

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ZEIER, H., G. TSCHANNEN, H. SEITZ AND A. FIDELER. *A device for wireless electric brain stimulation in operant conditioning situations*. PHYSIOL. BEHAV. 3 (4) 587–590, 1968.—A device for wireless electric brain stimulation was developed using an inductive transmission system. The device was tested with pigeons in an operant conditioning situation and the experimental data compared with results obtained with a wire stimulation system.

Electrical stimulation   Operant conditioning   Pigeon   Remote stimulation

ELECTRICAL BRAIN stimulation of conscious animals with chronically implanted electrodes has become a useful method in psychological investigations [8]. In behavioral studies a wireless stimulation system is often desirable; therefore several miniature transistor stimulators have been developed, using as stimulation energy either a battery [1, 5, 6] or the transmitter energy [3, 4]. Stimulation receivers light enough to be used for small animals have certain limitations: the stimulation cannot be monitored, no adjustments of the stimulation points are possible during the experiment, the electrical activity in the brain cannot be recorded, and, in the case of inductive transmission, the stimulation intensity may vary with changes in the orientation of the receiving antenna. By various compensatory measures, however, these disadvantages can be minimized and are then, in certain test situations at least, less critical than would be the disturbance to the animals caused by wire connections.

The present system was developed for wireless electric brain stimulation of pigeons in an operant conditioning situation. We chose an inductive transmission used industrially in wireless paging systems [7]. The device here described allows the stimulation current to remain practically independent of the momentary position of the animal as long as the antenna coil is prevented from occupying a position exactly perpendicular to the transmitter loop.

DESIGN AND CONSTRUCTION

Figure 1 shows the principal experimental set-up: a wire loop placed around the experimental cage is connected to the transmitter. The transmitter produces an alternating current of about 100 kc/s which generates a strong alternating magnetic field inside the area of the loop. The magnetic field outside the loop diminishes rapidly with increasing distance and therefore no precautions against interference with adjacent apparatus are necessary. The pigeon wears an antenna coil with the receiver around its neck. The magnetic field induces a voltage in this coil which is used for the stimulation of the brain. Maximum voltage is induced when the axes of the transmitter loop and antenna coil are parallel. An increase in the angle between these axes results in a decrease of the induced voltage according to a cosine function. At an angle of 90° no voltage is induced. In the present system the effects of this zero position were minimized by using sufficient transmitter power, receiver sensitivity and signal limitation in the receiver.

Transmitter

(Figure 1). For each stimulation pulse the continuous 100 kc/s sine wave from the oscillator is interrupted during a time E (Figure 3b) of 3–5 msec. This interruption time E and the repetition period F are set by the pulse generator. The remaining transmitter pulse length A must not decrease below the minimum value of about 2 msec, the time needed to charge the energy storage capacitor in the receiver. The pulse-modulated signal is amplified to the required level. This transmitter arrangement can be realized by currently available laboratory equipment.

Transmitter Loop

A homogeneous magnetic field in the test chamber may best be generated by using two wire loops, one at about the level of the surface on which the animal stands and a second one at the top of the cage. They are wired in series so that the current flows in the same direction in both loops (Fig. 1). Since metal parts of the cage may strongly distort the magnetic field, the cage should not be completely surrounded by wire screen and no metal plates should be in a plane parallel to

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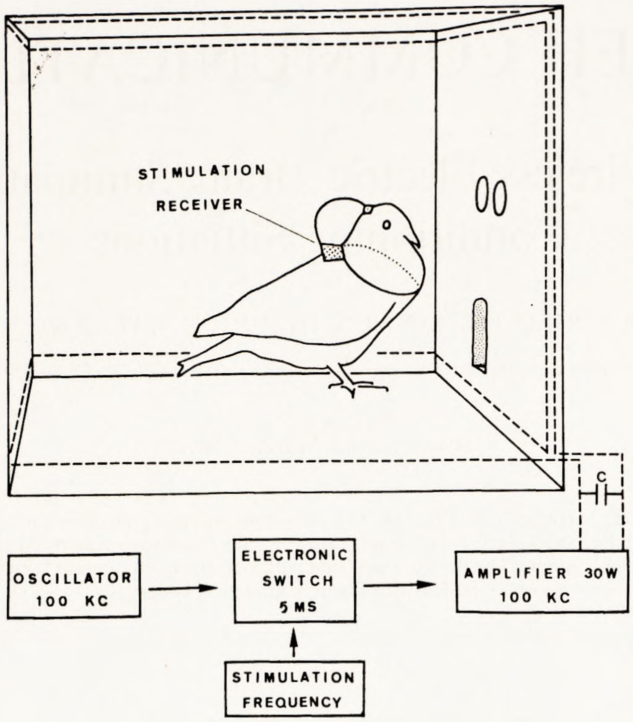

FIG. 1. Test cage with wire loops and transmitter for magnetic induction of brain stimuli. Specifications of the used loop: form: square with 38 cm sides; inductance: 1.9 μH; quality factor Q = 7.8; wire: copper enamelled, at least 1.8 mm dia. (A.W.G. No. 13); tuning capacitor C: 1.33 μF polystrene or polystrol, working voltage 200 V dc, operating current 20 A; resistance at resonance: 9.4 Ω.

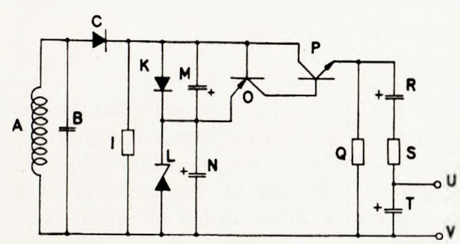

FIG. 2. Circuit diagram of the receiver. A: antenna coil (see Fig. 4); B: tuning capacitor, 2000 pF, miniature capacitor with polystrol dielectric (Styroflex); C, K: Germanium diodes OA95 (Philips); I: 1 Mohm, 1/10 W; L: Zener diode 22 V, ZF 22 (Intermetall); M, N, R, T: Tantalum dry electrolytic capacitors, 0.05 μF (Sprague 160D503D5015A); O: PNP-transistor, 2N3703, Silect (Texas Instruments); P: NPN-transistor, 2N3705, Silect (Texas Instruments); Q: 10 kΩ, 1/10 W; S: 5.6 kΩ, 1/10 W; U: positive terminal; V: negative terminal.

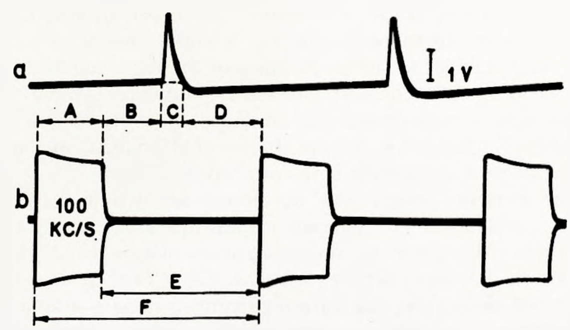

FIG. 3. a: Voltage at the terminals U and V of the receiver connected with a 2.2 kΩ resistor. b: High frequency signal of the transmitter. Symbols A–F: see text.

the transmitter loop. It is advantageous to use a test chamber made from insulating material. The transmitter loop is tuned with capacitors (Fig. 1) to the resonant frequency of the receiver which is about 100 kc/s. A transmitter power of 30 watts produces a current of 14 A_{rms} or 39 A_{pp} and a voltage of 17 V_{rms} or 47 V_{pp} in the transmitter loop described in Fig. 1.

Receiver

(Figure 2). The transmitter signal induces a voltage in the resonant circuit which is formed by antenna coil A and capacitor B. The induced voltage charges the capacitor N through the diodes C and K. The Zener diode L keeps the voltage of capacitor N at a constant value. The electric charge of capacitor N therefore remains constant and is independent of the momentary position of the pigeon. The voltage at capacitor M corresponding to the voltage drop at diode K cuts off the transistors O and P which means that no voltage is produced at the probe terminals U and V. During the 3–5 msec interruption time E of the transmitter signal (Fig. 3b) no voltage is induced in the resonant circuit A/B. Capacitor M discharges over resistor I to ground. Transistors O and P become conducting and discharge capacitor N through the pulse-forming network (capacitors R and T, resistors Q and S) and the load at the terminals U and V. A pulse (Fig. 3a) with an amplitude of about 2.5 V and 0.5 msec duration (C) is obtained when a 2.2 kΩ resistor is connected to the terminals U and V. The discharging time of the capacitor N is about equal to the pulse duration C. At the end of the pulse the transistors O and P return to the cut-off state and with the onset of the transmitter signal the described process is repeated. Only the charging time A of capacitor N is dependent on the signal amplitude of the transmitter, and is therefore critical in this process. For stimulation, the pulse intensity is adjusted with a resistor placed outside the receiver in series between terminal (U or V) and electrode. The pulse duration may be varied by changing the capacitors N, R and T. The minimum pulse period (e.g. maximum stimulation frequency) may be calculated by summing up the charging time A of capacitor N, the discharging time B of capacitor M and the pulse duration C (time D equal to zero). With the values given in Fig. 2 the maximum stimulation frequency is about 200 c/s. Figure 4 shows how the elements of the receiver are to be soldere together and cast in silicone rubber at the connecting end (the antenna coil. The weight of the complete receiver i cluding cable and plug is about 12 g.

EXPERIMENTAL RESULTS

The present system was checked against a previous exper ment in which a wire stimulation system had been used [10 The animals were required to peck a key for food-reinforc ment in an instrumental conditioning situation [9]. Th animals were first trained on a continuous reinforceme schedule until they performed sufficiently well. Two electrod were then symmetrically implanted in the brain and fixed t the skull with dental cement together with one indiffere electrode. After one week the animals were put on 20-mi sessions daily with a 1-min variable interval (VI) schedule (reinforcement [2]. For 5 days the animals were allowed t adapt to the receiver which was put around the neck an fastened under the wings by means of a harness of the typ used on messenger pigeons.

Stimulation trains of 30 sec duration were given durin the VI sessions. Animals stimulated bilaterally with 0.1 m in the archistriatum showed attention reactions, brief arrest in the pecking activity and a decrease in the instrumenta response rate (Fig. 5). These effects disappeared when th stimulation ceased. Stimulation of the same intensity in th

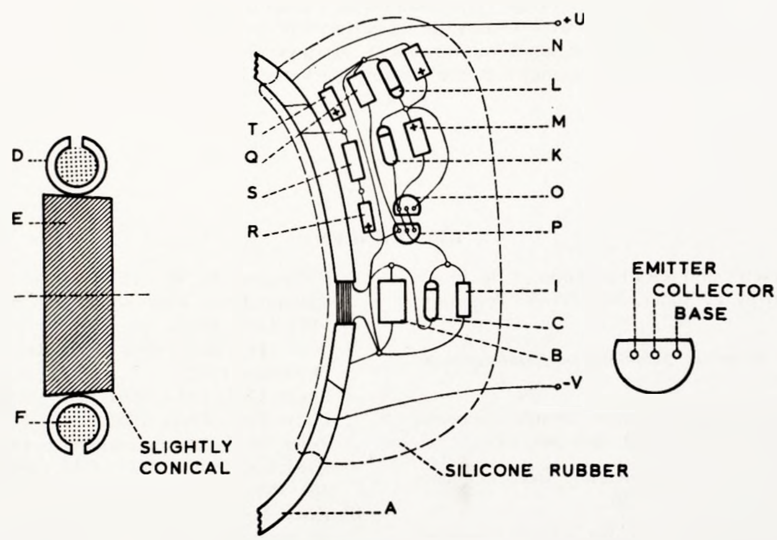

FIG. 4. Construction of the receiver. Left: antenna coil (inductance = 1.2 mH): 100 windings copper enamelled wire (F) with 0.15 mm diameter (A.W.G. No. 34) wound into a cut open plastic tube (D) of 4 mm diameter and 0.5 mm wall thickness by using a thorn (E) of 49 mm dia. After winding the plastic tube is closed and sealed.
Right: Arrangement of the receiver elements on the antenna coil. Abbreviations see text to Fig. 2.

neostriatum did not affect the response rate. These results correspond well with previous findings [10] obtained by a wire stimulation method.

Current and voltage of the stimulation were measured before and after each test session; the current with a Tektronix current-probe, the voltage directly with the oscilloscope. If the measured values are the same before and after one test session, it may be concluded that the stimulation parameters were constant throughout the whole session. In four animals the amplitude of the stimulation pulse remained relatively constant throughout a series of 10 successive sessions (one session daily).

The present system, which allows stimulation intensities up to about 1 mA, was used over a period of six months without any maintenance problems. The relatively modest cost of the receiver (approximately $4.00) will generally permit the use of an individually adjusted receiver for each animal.

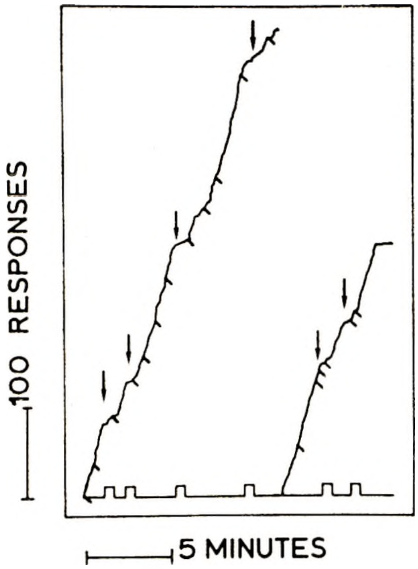

FIG. 5. Instrumental response rate of a pigeon stimulated in the archistriatum with 0.1 mA during performance on a 1-min variable interval schedule of reinforcement. Arrows above the response curve and rectangles at the bottom mark the 30 sec stimulation periods.

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