TECHNICAL NOTE

A CONTINUOUS RECORDING ACTIVITY CAGE

Unlike previously described capacitance sensing devices (Kavenau and Norris, 1961; McClelland, 1965), the present system utilizes the fact that when a parallel resonant LCR circuit, driven from a constant frequency source, is detuned, a phase shift is introduced between the driving voltage and the induced voltage. This phase shift is zero at resonance and varies sharply on either side of it, the rate of shift being determined mainly by the Q factor of the circuit. By comparing the phases of the two voltages, digitally small changes of capacity can be detected and recorded with a high degree of long-term stability.

The animal chamber, or cage, is so designed that the animal becomes part of the capacitive component of the resonant circuit. The animal's movements about the cage produce variations in capacitance that are sensed and recorded. The metallic food container and the nozzle of the water bottle are inserted into a ventilated Plexiglas lid and capacitively coupled to metal plates surrounding the cage. Contact with either of them produces a characteristic pattern on the recording chart, enabling identification of eating and drinking activities. The values of the capacities used in the present design are food container 170 pf, and the metal nozzle of the water bottle, 30 pf.

The cage (see Fig. 1), which is designed primarily for rats and mice, consists of a 14- by 11- by 6-in. plastic bowl containing a stainless steel grid raised 1 in. above the floor. Four aluminum plates are supported by plastic spacers so that they remain parallel with and about 1 in. from the cage walls. The four plates are electrically connected and together form one plate of the condenser. The animal makes electrical contact with

the floor grid in the cage and forms the other plate of the condenser. The cage is connected to the electronic circuitry by a low-capacity, shielded cable; the aluminum plates are kept at ground potential. The cage is thus well protected against stray capacitance effects and responds only to the movements of the animal. The metallic food container is placed in the centre of the bowl, the least sensitive or "dead zone" of the cage, thereby confining the animal to a symmetrical annular volume. Similar movements in any part of the cage produce identical changes in capacity.

The block diagram and essential circuitry used to detect the small changes of capacitance are shown in Fig. 2 and consist of the following sections:

(1) A crystal controlled oscillator, consisting of a single transistor, (T_1) provides a fixed-frequency sinusoidal waveform. The fundamental frequency of the crystal used in the present circuit is 285 Kc/sec, but any frequency between 250 Kc/sec and 1 Mc/sec could be used. Alternative designs may be used provided a reasonably stable and undistorted waveform is generated.

(2) The output of the oscillator is fed simultaneously, via a buffer stage (T_2 , T_{13}), into a Schmitt trigger circuit (T_{14} , T_{15}) and the drive (T_3) of a high Q tuned circuit, of which the animal chamber is a part. For a cage of the above dimensions and a crystal of up to 600 Kc/sec a dust core I.F. transformer (TR) is convenient for obtaining a reasonably high Q tuned circuit. The cage is connected across the secondary winding, and the condensers, in parallel with both the windings, are adjusted so that the circuit is just off resonance. The dust cores of the transformer serve as fine-adjustment tuning controls.

(3) A field effect transistor (F.E.T.) impedance converter circuit (T_4 , T_5 , T_6 , T_7) is used to sample the voltage across the resonant circuit without loading it. The design of the converter is not critical, and any circuit with an input impedance of about $10^6\Omega$ may be used.

(4) The output from the impedance converter is fed into a saturated amplifier (T_8 , T_9 , T_{10}) so that the variations in amplitude due to detuning, caused by the movements of the animal, are of no consequence. Any phase shift associated with the detuning may be detected by comparing this waveform with the output waveform from the Schmitt trigger circuit.

(5) The output waveforms from the Schmitt trigger and saturated amplifier circuits may be compared by shaping them to obtain pulses with a rise time of less than 0.1 microsecond (T_{11} , T_{12} , T_{16} , T_{17}). These sharp pulses are used to trigger a bistable circuit (T_{18} , T_{19}). Each pulse defines one stable state of the bistable, so

Fig. 1. Activity cage.

Fig. 2. Circuit (A) and block (B) diagrams. The waveforms are shown in the block diagram. There are 21 transistors in the circuit. T_4 is a field effect transistor type 2N3819 (Texas Inst., Bedford, England); T_5 , T_{12} , and T_{17} are type P346.A (S.G.S. Fairchild Ltd., Ruislip, Middlesex, England). The remaining 17 transistors are type V405. TR = 465Kc/sec. I.F. transformer; D_1 = 5.6 v zener diode; X = 285Kc/sec. piezo crystal; T = oscillator coil 300 turns, 20 S.W.G., 1 : 1 ratio.

that the ratio of the periodic time to the duration of the output waveform is governed by the difference in phase between the two pulses. When the two pulses are exactly in phase the bistable will not trigger; therefore, when an animal is initially introduced into the cage, the fine-tuning controls require adjustment. The onset of resonance may be monitored at the emitter of T_7 by an oscilloscope, a valve voltmeter, or 0.50 μ A microammeter preceded by a peak rectifier and a limiting resistance of about 0.1M Ω . In the present design, the adjustment required to produce reliable bistable triggering is achieved by setting the resonance monitor meter to a predetermined value. Any detuning caused by the movements of the animal produces a phase shift, and a corresponding change in the ratio of the periodic time to the duration of the bistable waveform.

(6) To derive a dc signal suitable for feeding into a potentiometer pen recorder, a simple integrating circuit (T_{20} , T_{21}) is required. A zener diode (D_1) in parallel with a condenser and a variable resistance are used to back off the quiescent potential at the emitter of T_{21} . With adequate current amplification a galvanometer pen recorder may be used. Total cost of components is approximately \$80.

The apparatus described has been used to record activity levels from both normal and immunosympathectomized rats and mice. The longest continuous recording period was over 26 days. Baseline drift was so small

that the zero of the recorder needed resetting only at four-day intervals, when the recording was interrupted for routine cleaning *etc.* Typical traces are shown in Fig. 3. Trace A (male mouse weighing 25 g), shows the characteristic alternating periods of net activity and sleep. Activity levels correlated with the estrous cycle of a female rat are illustrated in traces B, C, and D. The increases in net activity are similar to those found in activity wheels (Munn, 1950). Trace B was recorded from a female on the fourth day of her estrous cycle and shows the normal pattern of alternating periods of activity and sleep. Trace C was taken on the following day, at the animal's estrous peak, and shows the prolonged periods of activity. Trace D was taken from the same female five days after trace C, when high-level activity would again be expected to be associated with the estrous peak. The trace shows a pattern of prolonged activity similar to that found in trace C. Traces B, C, and D show corresponding time periods on the respective days. These large increases in activity correlated with the estrous cycle have been found to be confined to small circumscribed areas of the cage.

Trace E, with an expanded time scale, illustrates the characteristic pattern of the drinking response. Variations in the height of the trace are due to the animal altering its position. Hill and Stellar (1951) have reported that rats, over widely different levels of deprivation, lap at constant rates from the nozzles of water-

Fig. 3. Traces of typical recordings made by rats and mice in the activity cage. Trace A (male mouse, 25 g) shows characteristic alternating periods of net activity and sleep. Traces B, C, D, (female rat, 200 g): B taken on fourth day of estrous cycle, shows the typical irregular periods of activity; C, taken on fifth day of estrous cycle, shows prolonged net activity associated with the estrous peak; D, recording made five days after trace C, shows the prolonged activity of the following estrous peak. Trace E (male rat 240 g) shows drinking response pattern on expanded time scale. Trace F (male rat 300 g) shows eating (Y) and drinking (X) response patterns at normal recording speed.

bottles and consume constant amounts with each lap. With the present apparatus, and suitable paper speeds, it is possible to count the individual tongue laps. Results obtained show similar rates, 6 to 7 laps per sec, to those reported by Hill and Stellar. Trace F was recorded at normal paper speed and shows the characteristic patterns of eating and gnawing (Y) and drinking (X) responses. Periods of eating and drinking activity range from a few minutes in normal non-deprived animals up to periods of greater than 30 min for animals that have been deprived for some hours. It was necessary to limit the distance that the nozzle projected into the cage in order to prevent the animal from placing a paw upon it, an action which produced a change in capacity large enough to mask the actual drinking movements.

REFERENCES

- Hill, J. H. and Stellar, E. An electronic drinkometer. *Science*, 1951, 114, 43-44.
- Kavanau, J. L. and Norris, K. S. Behavior studies by capacitance sensing. *Science*, 1961, 134, 730-732.
- McClelland, W. J. An electronic apparatus for recording movements in small animals. *J. exp. Anal. Behav.*, 1965, 8, 215-218.
- Munn, N. L. *Handbook of psychological research on the rat*. New York: Houghton Mifflin, 1950.
- C. VAN-TOLLER¹ AND
A. DE SA^{2, 3}
*University of Durham and
University of Newcastle upon Tyne*
- ¹Reprints may be obtained from C. Van-Toller, Department of Psychology, University of Durham, Gillesgate, Durham, England.
- ²Author responsible for the electronic principle used. Department of Physics, University of Newcastle, Newcastle upon Tyne, England.
- ³The authors would like to thank A. M. Perry and M. G. Rolling, Department of Psychology, University of Durham, for skilled technical assistance.