AN ELECTROPHYSIOLOGICAL STIMULATOR WITH DIGITAL LOGIC

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Intracranial reward can conveniently be implemented by the use of digital logic. It has been used in such work with good results for two years. The basic configuration is as follows. The monostable multivibrator (OS-103) is triggered by the animal's response and controls the duration of the intracranial reward independently of the duration of the response. An astable multivibrator controls the basic pulse repetition frequency. In its turn it triggers a monostable multivibrator, the setting of which controls the duration of each individual pulse. The pulse train is normally set to last 0.5 sec by connecting an appropriate capacitor in the circuit of the monostable multivibrator. The repetition frequency generally employed is 100 ps, and the duration of each pulse is 0.1 msec. Each pulse is negative going. (As might be expected from the excitation of peripheral

nerve, the threshold of excitation with negative going pulses is lower than with positive.) In the system of digital logic used, the positive side of each logic card is grounded. It is therefore convenient to use the inverted output of the monostable multivibrator.

More complex waveforms are readily created. For instance, in order to measure the period during which the stimulated pathway is insensitive to a second pulse after excitation by the first, it is possible to set up stimulation with pulse-pairs. The repetition rate of the double pulses is kept uniform while the interval between the pulses in each pair is varied. An astable multivibrator triggers a monostable multivibrator (the output from this forms the first pulse in a pair). This monostable multivibrator at its offset triggers another monostable multivibrator. (The function of this unit is to

provide an interval between the pulses in each pair.) This card has a range of capacitors connected to it, and the 'on' time may conveniently be selected by a switch. The offset of this unit triggers the third monostable multivibrator. (This last multivibrator provides the second pulse in each pair.) The negative going outputs from the first and third monostable multivibrators are fed into an 'and' gate, which, according to De Morgan's theorem, functions as an 'or' gate when negative pulses are inserted. The output of this can then be fed to the electrode through a coupling device. The times to which the units are set are the same as those described above.

The coupling device to the electrodes is basically a conventional capacitative ac coupling. First the output from the 'and' gate is connected to one end of a potentiometer. The other end is connected to the positive of the unit (which is normally tied to ground). The variable output from the potentiometer is fed into a capacitor ($0.5 \mu\text{fd}$). This is connected to the instrument positive via a 22K resistor and also to one electrode. The indifferent electrode is connected to the instrument positive (normally grounded). Because of the ac coupling there is no net current flow in one direction. Very stable results with rates of lever pressing or thresholds have been obtained with this mode of stimulation over a period of weeks with the same animal. No damage of tissue surrounding the electrode was apparent on histological examination.

The system has a particular advantage over more conventional methods when used as a stimulator during electrophysiological recording. In order to reduce stimulus artifact, the stimulator and the recording amplifier should

be decoupled as far as possible. This is normally achieved by the use of radio-frequency transformers. In the present system, decoupling is achieved simply by the use of a 12 v battery or accumulator which is left floating, as a power source. Such a system has been used with good results.

When the rest of the programming equipment is transistorized and no circuits are being broken through inductive loads, no transients occur to be picked up by the leads to the animal. Constant monitoring has disclosed no need to interrupt the circuit to the animal when pulse trains are not being delivered.

It should be pointed out that substantial freedom from distortion of the monophasic pulse is obtained in the present circuit because of the relatively long time-constant of the coupling circuit (3.4 msec, assuming that the rat's resistance is 10K). If, however, the pulse is lengthened or the time-constant shortened, distortion of the pulse will become increasingly prominent. Instead of maintaining its negativity (and so remaining horizontal on the oscilloscope display) the crest of the pulse will slope back towards zero voltage. In a similar way when the pulse is turned off, it will overshoot zero voltage and produce a deviation in the positive direction. Further, in the present arrangement the mark-to-space ratio is 1 to 100 or 1 to 50. The resultant output is therefore monophasic to a good approximation, given the long time-constant of the circuit. If the mark-to-space ratio approaches 1 to 1 the output also becomes effectively biphasic. However, brief monophasic pulses are preferred as their electrophysiological interpretation is more straightforward.