An inexpensive integrated circuit intracranial stimulator

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An intracranial stimulation unit which offers precise control of stimulus duration, frequency, and current is described. The unit generates a square wave stimulus output utilizing very inexpensive, easily constructed integrated circuitry.

Commercially available stimulators which allow the experimenter to control pulse train frequency, duration, and amplitude may cost several hundred dollars or more.¹ This report describes an integrated circuit stimulator that permits control of the above parameters, yet can be constructed for under \$25.00. The chief constraint of the proposed circuit is that the stimulus waveform is not selectable; the pulse train provided is a fixed 50% duty cycle biphasic square wave. More elaborate waveforms, such as the biphasic pulse-pair advocated by Lilly (1955), require more elaborate circuitry. However, the 50% duty cycle square wave employed in the present design has two advantages when compared with shorter pulses: it allows the use of lower voltages to achieve required coulomb thresholds at the electrode site (Mickle, 1961); and, it facilitates computation of peak current reaching the electrode site during stimulation. This design can be used in student laboratories and general experimental work where variation of the stimulus waveform is not necessary.

A schematic of the stimulator is shown in Figure 1. The circuit utilizes two LM 555 integrated circuits², one in monostable (IC1) and one in astable (IC2) multivibrator configuration. Upon shunting of the trigger input to ground (by the closing of a microswitch, for example), IC1 is set to produce a pulse of given duration, determined by R_D . A 10-k Ω resistor prevents spurious triggering by "pulling up" the open trigger input of IC1 Pin 2, to +V.

The R-C circuit formed by the 2.2-M Ω resistor and .015- μ F capacitor limits the triggering to only one pulse from IC1 regardless of the length of time that the trigger inputs are shunted. The sustain switch bypasses the R-C circuit and allows continuous-duty operation of IC1 by grounding input Pin 2.

The pulse from IC1 Pin 3 powers both the stimulus on light-emitting diode (LED 2) and astable IC2. IC2

generates the square-wave pulse train that constitutes the intracranial stimulus. This arrangement is fully capable of generating frequencies from 10 Hz to 10 kHz, depending on the selection of a suitable C_F .

The square wave output from Pin 3 of IC2 varies from ground to +V. Such a unidirectional square wave has been found to cause electrolytic tissue damage at the intracranial electrode site (Mickle, 1961). In the present circuit, the unidirectional dc (direct current) square wave is transformed into an ac (alternating current) waveform. This is achieved by referencing the Pin 3 output not to ground, but to +V/2 via a voltage divider circuit composed of two 2.2-k Ω resistors. The stimulus at the electrode is thus a true ac stimulus with voltage varying from +V/2 to -V/2. Additionally, the voltage divider circuit serves to current-limit the output of IC2 to under 5 mA, rendering the circuit impervious to damage due to shorted stimulus outputs. The two voltage divider resistors should be closely matched to minimize dc offset at the electrode site.

Stimulus current is adjusted via the .5-M Ω potentiometer. Further, the current delivered to the electrode may be read off the 0-100 dc microammeter connected to the full-wave diode bridge as shown. The diode bridge enables the use of an inexpensive dc meter movement; ac microammeters are prohibitively expensive for this application. Since IC2 operates on a 50% duty cycle (symmetrical) square wave, current read from the meter equals one-half the current being delivered to the electrode site.

In intracranial stimulation research, it is important that stimulus current be relatively constant despite the impedance changes expected with chronic preparations. In this stimulator a large resistance, the .5-M Ω potentiometer, is placed in series with the electrode in order to adjust, and to regulate stimulus current. Any change in the electrode/tissue impedance, therefore, is a small proportion of the total load impedance presented to IC2. For example, assuming an electrode/tissue impedance of 15 k Ω , and a setting of the potentiometer such that its resistance is 250 k Ω , the total load impedance

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NOTE: ALL CAPACITANCES ARE IN MICROFARADS.
ALL RESISTORS ARE 1/4W 10% EXCEPT WHERE
OTHERWISE NOTED.

Figure 1. Circuit diagram of the intracranial stimulation unit.

presented to IC2 is 265 kΩ. Even if the impedance of the preparation increases by one-third, to 20 kΩ, total load impedance only increases to 270 kΩ. Since in a series circuit current in any part of the circuit is a function of the total circuit impedance, current at the electrode site decreases by only 2% [(256 kΩ-270 kΩ)/265Ω]. Thus for practical intensities of stimulation, current regulation is quite satisfactory. The operation of IC2 itself is relatively independent of wide variations in electrode impedance.

Power supply requirements for this circuit are not critical. Any 12-18 V dc supply capable of producing 300 mA, and with some filtering, will work. The circuitry is compact and, excluding power supply, can easily be placed on one 4 x 6 in. printed circuit card, although lead dress is not critical and point-to-point wiring may be used effectively. If possible, the stimulator ground should "float" free from the conductive elements of the animal's cage.³

Table 1
Values for C_F for Varying Stimulus Frequencies

C_F (Microfarads)	Frequency (Hz)
.0033	1000
.005	750
.0075	500
.01	350
.02	200
.027	120
.033	100
.075	60

Stimulus duration and frequency are determined by appropriate selection of duration resistor R_D and frequency capacitor C_F . These parameters have been shown to influence substantially responses induced at specific electrode sites (Ervin & Kenney, 1971).

In our laboratory, the prototype stimulator employed six-position switches for R_D and C_F , such that stimulus duration could be varied from .05-1.0 sec. and frequency from 60 Hz to 1 kHz.

C_F should be determined first. Use a temporary value of 1 MΩ for R_D . Close the sustain switch and shunt the trigger inputs; this turns IC2 on indefinitely. The use of a digital frequency counter is highly recommended, and is connected to the stimulus outputs for this measurement. If such a counting meter is not available, the stimulus outputs may be connected directly to 600-Ω headphones. The stimulus frequencies can then be calibrated with an audio generator by "beating" the stimulus output frequency against the generator frequency. The frequencies match when the beat frequency is 0 Hz. Values of C_F are selected for the frequencies desired; approximate values for different frequencies are shown in Table 1. Precise frequency determinations will require addition of appropriate "gimmick" capacitors either in series or parallel with C_F . In general, a close approximation for C_F can be obtained from the formula:

$$F(\text{Hz}) = \frac{1}{251K(C_F)}$$

Table 2
Values of R_D for Varying Stimulus Durations

R_D (Ohms)	Duration (Sec)
220 K	.05
430 K	.1
850 K	.2
1.3 meg	.3
1.7 meg	.4
2.0 meg	.5

Inexpensive disk capacitors were employed, and yielded a frequency stability of ± 3 Hz. Stability may be greatly improved by using more expensive mylar capacitors.

Precise determination of R_D is best accomplished using a digital counter. The sustain switch is opened. The counter is again connected to the stimulus outputs. The number of square wave pulses for a given frequency (already established by C_F) and duration is calculated. For instance, if the operating frequency of IC2 has been chosen to be 100 Hz, then a .5-sec stimulus duration will yield 50 square wave pulses at the outputs, for each triggering event. Thus the correct value of R_D is that which will produce a count of 50 on the digital counter each time the trigger inputs are shunted. Approximate values of R_D for varying stimulus durations are noted in Table 2. In general the appropriate value for R_D can be calculated using the formula:

$$R_D = \frac{D_S}{.235},$$

where R_D is expressed in megohms and D_S is the desired stimulus duration in seconds.

Table 3 includes all the componentry needed to construct the stimulation unit.

It should be noted that a pulse indicating stimulus onset and duration may be derived from Pin 3 of IC1. This pin is normally at ground potential, and rises to +V during stimulation. The pulse may be used directly, or divided as appropriate, for input to an event recorder, computer interface, or any other device which draws no more than 50 mA.

The trigger inputs may also be connected directly to a TTL interface; TTL "0" activates the stimulator. Thus, stimulation can easily be brought under computer control.

Table 3
Parts List for the Intracranial Stimulation Unit

Quantity	Component
2	LM555 integrated circuit
4	1N4148 silicon diode (or equivalent)
2	light emitting diode
2	270 Ω ¼ W 10% resistor
1	1.5 k Ω ¼ W 10% resistor
2	2.2 k Ω ¼ W 1% resistor
1	10 k Ω ¼ W 10% resistor
1	180 k Ω ¼ W 10% resistor
1	2.2 M Ω ¼ W 10% resistor
1	.5 M Ω linear taper potentiometer
1	R_D (see text)
2	.01 μ F 50 V dc (ceramic or mylar)
1	.015 μ F 50 V dc (ceramic or mylar)
1	.22 μ F 50 V dc (ceramic or mylar)
1	C_F (see text)
1	Power supply, 12-18 V dc, 300 mA
2	SPST toggle switches
1	0-100 dc microammeter

REFERENCES

- ERVIN, F. R., & KENNEY, G. J. Electrical stimulation of the brain. In R. D. Myers (Ed.), *Methods in psychobiology*. New York: Academic Press, 1971. Pp. 233-237.
- LILLY, J. C., HUGHES, J. R., ALVORD, E. C., JR., & GALKIN, T. W. Brief, noninjurious electric waveform for stimulation of the brain. *Science*, 1955, **121**, 468-469.
- MICKLE, W. A. The problem of stimulation parameters. In D. E. Sheer (Ed.), *Electrical stimulation of the brain*. Austin, Texas: The University of Texas Press, 1961. Pp. 64-67, 70.

NOTES

1. Exemplary are the Haer 4B Digital Stimulator with Optical Isolator 74-60-1 (\$945.00); and the W-P Instruments Model 302-T Anapulse Stimulator, with two Model 305-2 stimulus isolation units to obtain a bipolar waveform (\$1,410.00).

2. The LM 555 integrated circuit is commonly available at Radio Shack outlets at \$1.49 per chip. The IC is also available as NE 555V from James Electronics, P. O. Box 882, Belmont, California 94002, at \$.70 per chip. The 555 IC is also available as a dual chip, LM 556 N. It is not recommended for this application, however, since it is more expensive than two LM 555s and since failure of one section of the 556 necessitates replacement of the entire IC.

3. "Floating" the stimulator ground from the cage floor and manipulanda assures that no DC offset voltage will arise during stimulus presentation, due to the offset correction induced by the voltage divider circuitry. Studies in our laboratory, however, indicate that any offset introduced from the electrode site through the animal's body to a grounded cage floor is negligible, amounting to offsets less than 3 microA.

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