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A CONSTANT-VOLTAGE AND CONSTANT-CURRENT STIMULUS ISOLATION UNIT

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When action potentials from a stimulated biological preparation are recorded it is essential to isolate the stimulus resistively and capacitively from the ground in order to minimize stimulation artifacts. Such isolation can be achieved by using a transformer of special low-capacitance construction in the output of a stimulus generator (Donaldson 1958). The most widely used arrangement for the isolation, mentioned previously, is the Schmitt-type isolation unit (Schmitt 1948). It consists of a driven radio-frequency oscillator with its output rf link coupled to the preparation. The most recent isolation units are based on the light transmission of electrical stimulus from the generator to the preparation (Dawson et al. 1960, Ross and Bassett 1967).

By using the stimulus isolation unit in the output of a stimulus generator, the stimulating current flows entirely between stimulating electrodes, whether the preparation is grounded or not. When, however, electrodes made of thin wire (usually of 0.1 or 0.2 mm in diameter) are used, in this case for intracerebral stimulation of laboratory animals, the stimulus yields to appreciable distortion. When the constant-voltage type stimulus isolation unit (device with low output impedance) is used a current pulse yields to distortion. It is caused by the electrochemical polarization of the electrodes used for stimulation (Weinman and Mahler 1964, Greatbatch 1967). The small contact areas of the electrodes with the preparation are the cause of high current densities at the metal-preparation interface, resulting in electric polarization with the electrode behaving as a capacitance. The typical distortion of a rectangular current pulse is shown in Fig. 1b. This distortion makes the measurement of the stimulating current difficult. Since it is generally accepted that

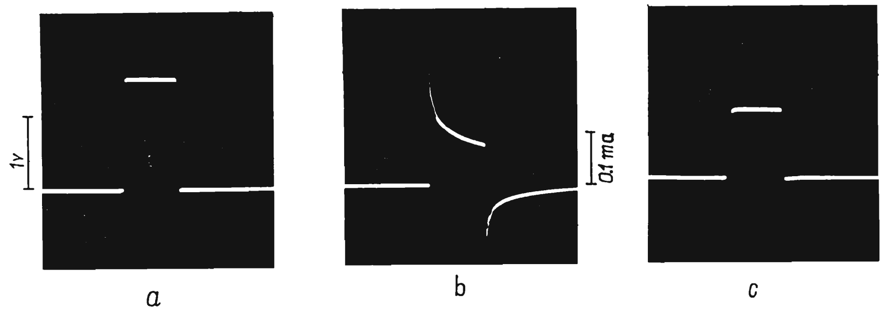

Fig. 1. Oscilloscope tracings showing: a, constant-voltage pulse; b, current pulse during constant-voltage stimulation; c, current pulse restored to a near-rectangular shape. Photographs were taken while stimulating a rabbit through permanently implanted subcortical platinum electrodes having a diameter of 0.2 mm. Distance between electrodes, 1 mm. Pulse duration, 1 msec.

a very relevant parameter for stimulation of a biological preparation is the applied current, its accurate measurement is necessary (Mickle 1961, Becker et al. 1961, Olds 1962). To eliminate this distortion and thereby to achieve a rectangular pulse permitting accurate measurement, the constant-current stimulus isolation unit would be preferable. A simple way to achieve approximate constant-current conditions would be to place a high resistance in series with the stimulating preparation, but this limits severely the maximum obtainable current. One of the ways to solve this problem is application of a pentode in the circuit of the isolation unit (Allison et al. 1967). Here an inherent property of the pentode is used to that, within limits, the plate current is virtually independent of changes in load impedance. A transistorized constant-current converter can also be used (Bignall 1963). The converter takes advantage of the fact that the collector current of a common base transistor is essentially independent of load resistance. As a result, changes in the impedance caused by electrochemical polarization of electrodes have little effect on the stimulus current. Another way of achieving approximate constant-current conditions is the equalizing of the capacitance of the electrode-preparation combination with an inductance connected in series into the circuit of the isolation unit and the preparation (Mundl 1966). However, rectangular current pulses are obtained at the cost of voltage pulse distortion.

To eliminate errors from the measurement of stimulation parameters and from the interpretation of results obtained it is necessary to use electrical pulses of a constant voltage and current during stimulation. For this purpose a stimulus isolation unit providing constant-voltage or constant-current pulses was constructed (see diagram, Fig. 2).

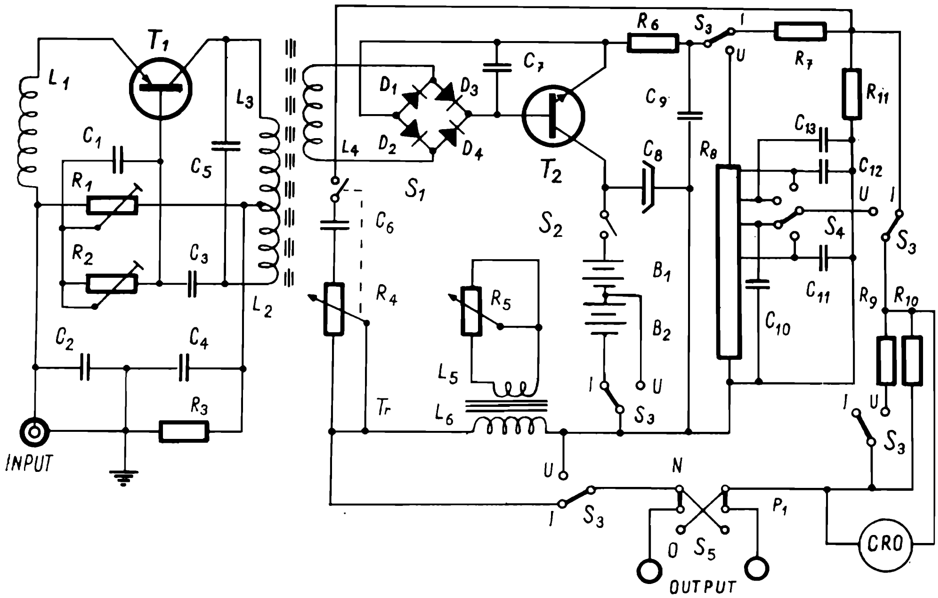

Fig. 2. Circuit diagram of constant-voltage and constant-current stimulus isolation unit

RESISTORS

R_1 — 150 kΩ 0.5 W (composition)	R_7 — 500 Ω 4 W (wire)
R_2 — 2.5 kΩ 0.5 W (composition)	R_8 — 800 Ω 6 W (wire)
R_3 — 500 Ω 1 W (composition)	R_9 — 500 Ω 4 W (composition)
R_4 — 47 kΩ 0.5 W (composition)	R_{10} — 2 kΩ 2 W (composition)
R_5 — 100 Ω 4 W (wire)	R_{11} — 20 kΩ 1 W (composition)
R_6 — 50 Ω 6 W (wire)	

CAPACITORS

C_1 — 0.05 μF 250 v (paper)	C_8 — 400 μF 200 v (electrolytic)
C_2 — 700 pF 500 v (ceramic)	C_9 — 400 pF 250 v (ceramic)
C_3 — 100 pF 500 v (ceramic)	C_{10} — 6.8 nF 250 v (ceramic)
C_4 — 0.15 μF 150 v (paper)	C_{11} — 10 nF 250 v (ceramic)
C_5 — 75 pF 200 v (ceramic)	C_{12} — 1 nF 250 v (ceramic)
C_6 — 0.15 μF 250 v (paper)	C_{13} — 3.3 nF 250 v (ceramic)
C_7 — 150 pF 400 v (mica)	

T_1 — TG10 germanium pnp transistor (TEWA, Warsaw) or OC45 (Philips) 2N218 (Hitachi)

T_2 — 2N2988 silicon npn transistor (Texas Instruments) or BUY52 (TEWA)

D_1, D_2, D_3, D_4 — DOG 58 germanium diodes (TEWA, Warsaw)

L_1 — 1.5 mH rf choke

L_2 — coil: 8 turns on a 16 mm diameter former (enamelled copper wire 0.1 mm in diameter)

L_3 — coil: 24 turns on a 16 mm diameter former (enamelled copper wire 0.1 mm in diameter)

L_4 — coil: 90 turns on a 18 mm diameter former (enamelled copper wire 0.1 mm in diameter)

Tr — transformer: primary winding (L_6) — 30 H, 1.8 kΩ; secondary winding (L_5) 80 mH, 17 Ω

B_1, B_2 — 67.5 v batteries

The stimulus isolation unit presented above operates as follows: the pulses from the stimulus generator provide power for a radio-frequency oscillator, the rf oscillator being a transformer coupled to a rectifier which converts the oscillations back to d-c pulses. These pulses operate a transistorized voltage switch connected with the output circuit.

The rf oscillator is a Hartley circuit. Its frequency is about 2 MHz. The coils of the resonant circuit L_2, L_3 are wound together with a coupling coil L_4 on the same annular ferrite core 8 mm in diameter. The distance between L_2, L_3 coils and L_4 coil is 8 mm. The inductive coupling of the L_4 coil and its low coupling capacitance (about 3 pF) assure a proper isolation of the electrical pulse from the ground. Rf voltages appearing on the coupling coil L_4 are rectified and applied to the base of the T_2 transistor. In this system the T_2 transistor (2N2988 npn silicon transistor) acts as a voltage switch and it conducts only during the action of the triggering pulse from the stimulus generator. The pulse for triggering the isolation unit must be approximately 1.5 v or higher but less than 15 v. The 2N2988 transistor is capable of handling a collector-emitter voltage up to 155 v. This transistor is powered by two 67.5 v batteries (B_1, B_2).

If the S_3 switch is in U position the isolation unit provides constant-voltages pulses during stimulation (Fig. 1a). The voltage pulse from the T_2 transistor is directed to the voltage divider R_8 with a four position switch S_4. The S_4 switch sets maximum output voltage values of 2, 4, 10 and 20 v. Each of these voltages can be continuously varied from zero to maximum by changing the pulse amplitude of the driver. The output resistance for the 2 v range is 80 Ω and for 4, 10 and 20 v ranges, 160 Ω, 400 Ω and 800 Ω, respectively. This stimulus isolation unit produces constant-voltage pulses when the load resistance is over 1 kΩ for the 2 v range, and when the load resistance is over 5 kΩ, 30 kΩ, and 50 kΩ for 4, 10 and 20 v ranges, respectively (see diagram, Fig. 3). The radio-frequency component at the output is eliminated by the C_7, C_9, C_{10}, C_{11}, C_{12} and C_{13} capacitors. The stimulus current can be measured by measuring the voltage drop across R_9, and R_{10} resistors. A double pole, two position switch S_5, permits changes in the output pulse polarity (N, normal polarity, O, reverse polarity).

By setting the S_3 switch in position I constant-current pulses are

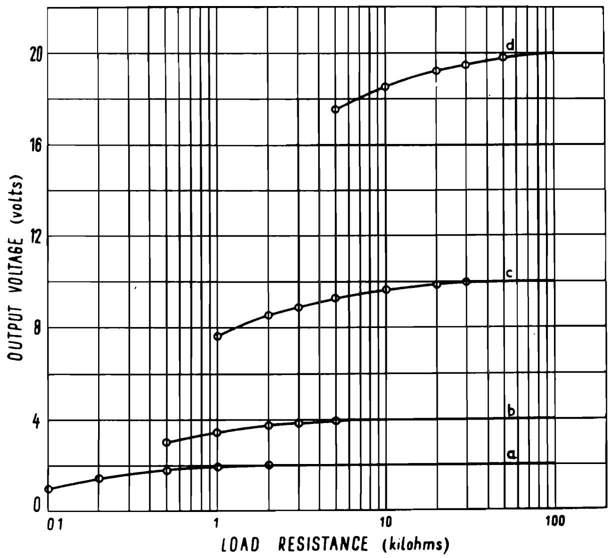

Fig. 3. Diagrams illustrating output voltage decrease of constant-voltage stimulus isolation unit in relation to load resistance. Output resistane: a, 80 Ω; b, 160 Ω; 400 Ω; d, 800 Ω

obtained during stimulation. In this case a transformer (Tr) is connected in series into the output circuit. Fig. 2 shows the circuit arrangement. The primary winding of the Tr transformer presents an inductive reactance to the leading edge of the pulse. A variable resistance R_5, across the secondary winding permits variation of the inductive reactance of the primary winding. With the proper adjustment of the inductive reactance value, a voltage pulse can be formed so that the current will be approximately constant during stimulation (Fig. 1c). Depending on the layout of the wiring of the experimental set-up, an overshoot at the beginning and the end of the pulse may occur due to stray capacitance. This can be eliminated by the R_4C_6 network (Fig. 2), where R_4 and C_6 are selected for optimum performance dependent on an experimental set-up. The possibility of restoring the current pulse to a near-rectangular shape facilitates the measuring of the pulse amplitude with a cathode ray oscilloscope. A CRO with differential input or an amplifier with radio-frequency output is required when applying a stimulus isolation unit (Kądziela 1967, Tomaszewski and Kądziela 1968). The described circuit acts satisfactorily with thin wire electrodes an stimulation currents ranging from a few μa to 10 ma (see diagram, Fig. 4). The stimulating current can be continuously varied from zero to maximum by changing the pulse amplitude of the driver. The d-c output voltage in

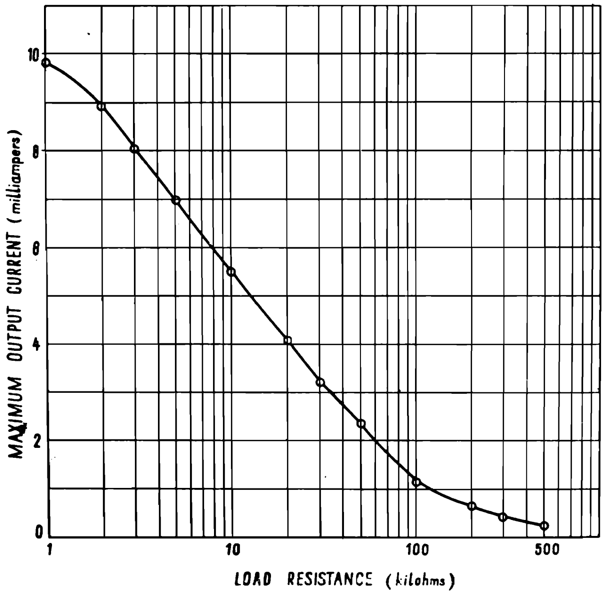

Fig. 4. Diagram illustrating maximum output current of constant-current stimulus isolation unit in relation to load resistance

the intervals between 120 v pulses is less than 0.2 mv and the radio--frequency component is not marked.

SUMMARY

A stimulus isolation unit that provides constant-voltage pulses ranging from zero to 20 v or constant-current pulses ranging from a few microamperes to 10 ma is described.

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