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A modified "triangular pulse" stimulator for C-fibers stimulation

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A low-cost, battery-powered stimulator is described. This device generates asymmetric current pulse with fast rising phase and slower exponential decay. The current intensity and the time constant of the exponential decay can be independently and continuously varied. An example of using this stimulator to selectively activate C-fibers is demonstrated. In this case the total charge injected in one stimulation is only 67 nanocolumb, which is much smaller than that injected by conventional DC polarization technique. Detailed information about the circuit design is described.

Introduction

C-fibers play a major role in the transmission of nociceptive and temperature information. Yet the temporal and spatial distributions of central responses evoked by C-fibers remain unclear. One of the prerequisites to address these questions is that C-fibers must be activated selectively without contamination from A-fibers. There have been many methods utilized to activate C-fibers selectively, for example, temperature (Paintal, 1965), pressure (Gasser and Erlanger, 1929), AC (Tanner, 1962) or DC current (Brown et al., 1975) and voltage pulses of various waveforms (Zimmermann, 1968; Accornero et al., 1977). However, owing to technical difficulties and dissatisfication in performance a simple and reliable method is still needed. For the time being, DC polarization is the most widely used method. However, there are several drawbacks in this method. A separate pair of electrodes in addition to the stimulus electrode is required to deliver the polarizing DC current, thus more space is needed. This factor makes it very difficult to apply DC polarization method in short nerves, such as the dorsal roots of rats. Secondly, it is not a very reliable and reversible method owing to injection of a large amount of charge during the period of polarization.

Anodal block technique utilizing asymmetric pulse has been used to elicit pure C-fiber response. Usually, a pulse with fast rising phase and slower exponential decay is used. This is first achieved by Burke and Ginsborg (1956). The purpose of this waveform is to avoid break excitation at the anode caused by square-wave pulse. The effects from pulses of this waveform on peripheral nerves were evaluated in detail by Accornero et al. (1977). However, we were not successful utilizing the circuit in their paper (Figure 1 in Accornero et al., 1977) to activate C-fibers without contamination of A-fibers. Their design, although simple, has two major problems. First, high frequency noise in the stimulating pulse cannot be totally eliminated.

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Second, the amplitude and the decay time constant of the stimulating pulse cannot be changed continuously and independently. Therefore, a stimulator with independent controls of amplitude and decay time constant was developed. It was battery-powered to eliminate the problem of electrical interference from AC power line. Also, constant current design was implemented.

Materials and methods

Figure 1 shows the complete circuit diagram of the stimulator. For battery application, low-power design includes the use of low static current ICs and high impedance passive components. This circuit can be partitioned into three parts: a pulse generator, a waveform shaper and an external trigger. Two CMOS timing devices (ICM7555 and CD4528) are employed in the pulse generator. In the waveform shaper two amplifiers (A1 and A2) are used to buffer and convert the voltage waveform into current output. The third part is the trigger output of the stimulator which consists of a photocoupler (HCPL-2530) and an amplifier (A3) to isolate and buffer the trigger pulse.

In the pulse generator the ICM7555 is programmed as an astable multivibrator. The frequency of oscillation is about 0.1 Hz (determined by the 120 MΩ resistor and the 0.1 μF capacitor). Stimulating frequency higher than this value is not recommended because C-responses in the central nervous system may "wind-up" (Schouenborg, 1984). For the purpose of adjusting the amplitude and the decay time constant of the output waveform conveniently, the frequency of the stimulator can be increased to 1 Hz by switching to the 12 MΩ resistor when the output is in the monitor position. The CD4528 is a two-circuit-in-one package monostable multivibrator. One of them is used as a delay circuit. Maximun delay is 10 ms. The purpose of the delay circuit is to pretrigger

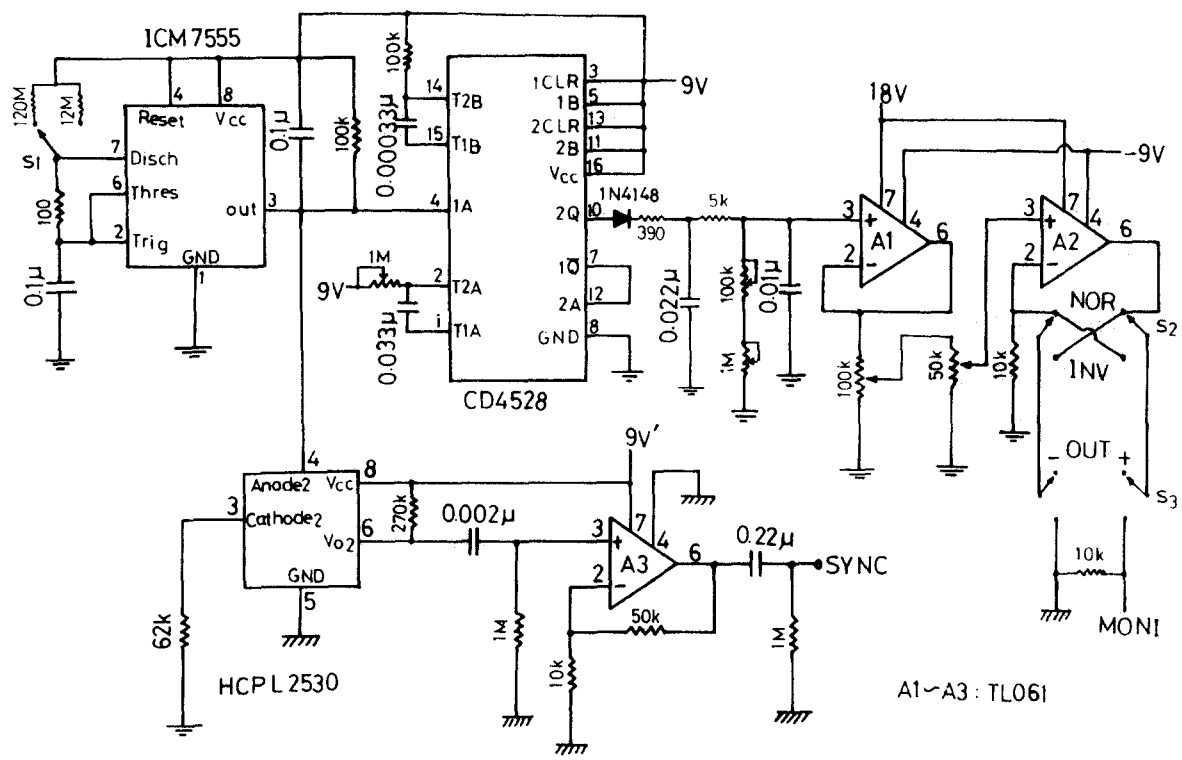

Fig. 1. Circuit diagram of the stimulator. A1–A3: TL061.

the oscilloscope and the analog-to-digital card to acquire the peristimulation response. Output of the other multivibrator is a 20 μs pulse. Following this pulse is the waveform shaper. The diode in this part is for the purpose of preventing current backflow when the pulse changes from positive to 0 V. This waveform is then filtered by two pairs of RC networks to eliminate the high frequency noise which occurs at the transient edges of the pulse. The amplitude of the output waveform can be adjusted continuously by the 100 kΩ (course) and 50 kΩ fine (ten-turn) variable resistors. The time constant of the exponential decay can be adjusted by the 1 MΩ (course) and the 100 kΩ (fine) variable resistors. To increase the output range, the amplifiers A2 and A3 are powered by a higher positive source (+18 V) than that of the negative source (−9 V), which is used to properly bias the amplifiers. The output current range is dependent on the impedance of the nerve segment between the two stimulation electrodes. For example, for a 20k ohm nerve segment, the maximal output current is 18 V/(20 kΩ + 10 kΩ) = 0.6 mA. The last part of the stimulator is the trigger circuit for external synchronization. The stimulator is isolated from the recording ground by the photocoupler, HCPL-2530. The output pulse of the photocouple is then amplified and buffered to TTL level by the amplifier A3. The photocoupler and the amplifer A3 were powered by a separate 9 V source (+9 V′). In addition, absolute isolation was guaranteed by using a plastic case to enclose the stimulator.

Results

Figure 2 shows an example of the application of this stimulator. The experimental setup is shown

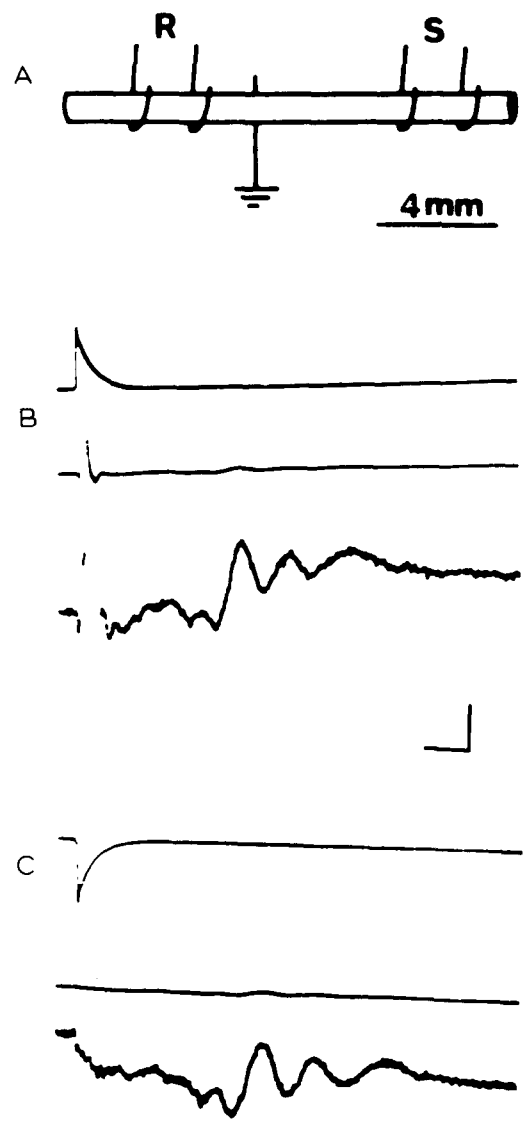

Fig. 2. An example of selective activation of the C-fibers with the stimulator. (A) Experimental setup. An isolated piece of the dorsal root of the sixth lumbar spinal cord of a rat was used. At normal polarity, the cathode of the stimulator was closer to the recording electrode than the anode. At inverse polarity, the anode was closer. (B) Normal CAP evoked with normal polarity. Top trace: monitor output; middle trace: low-gain AC recording (bandpass: 0.1 Hz to 10 kHz); lower trace: high-gain AC recording. The waveform of the stimulus can be seen from the monitor output. It had an amplitude of 37 μA and a decay time constant of 1.8 ms. The full A wave can be seen in the middle trace. Its peak-to-peak value was 7.7 mV which was out of scale in the lower trace. The lower trace shows the C components of the CAP clearly. It had several components, the highest peak-to-peak value was 0.26 mV. (C) Selective activation of the C fibers with inverse polarity. Arrangements of the traces are the same as in B. No trace of the A component can be seen in the CAP even in the high-gain trace (lower trace). The C components were largely unchanged. Calibrations: horizontal bar: 5 ms, vertical bar: 29 μA for the top, 2.9 mV for the middle and 0.14 mV for the lower traces.

in Fig. 2A. Supramaximal intensity for C-fibers was used. With stimulation pulse of normal polarity (cathode near the recording electrode) a normal compound action potential (CAP) was obtained. It composed of summed potential from fibers of the A group and the C group (Fig. 2B). Fig. 2C shows the result of selective activation by inverting the stimulating pulse (anode near the recording electrode). The CAP of the A-fibers was blocked completely but that of C-fibers remained.

Discussion

A battery-powered stimulator which generates asymmetric constant current pulses with continuous and independent controls of amplitude and decay time-constant was presented. In Fig. 2 the time constant of the stimulating waveform is 1.8 ms and the amplitude is 37 μA. In this condition the total charge injected is only 67 nanocolumb. In comparison, for the purpose of DC polarization, constant current of several hundred μA were delivered for several seconds. We were able to keep the nerve in good condition for at least 3 h with one shock every 10 s. Futhermore, the inter-electrode distance of the stimulating electrode was only 2 mm, not only shorter than required by DC polarization but also shorter than those used by Accornero et al. (1977). Thus, simpler surgical preparation was required with this method. This stimulator needs low-power (0.4 mA), it is low-cost and easy to use. It should find wide applications in neuroscience.

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