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An inexpensive, charge-balanced rodent deep brain stimulation device: A step-by-step guide to its procurement and construction

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HIGHLIGHTS

- The device has an extremely long lifetime with typical stimulation parameters.
- The device is initially fully programmable in frequency, pulse-width and current amplitude allowing the study of any common stimulation paradigm.
- Two independent outputs are charge-balanced ensuring zero net current delivery per period.
- The device is inexpensive and easy to replicate.

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ABSTRACT

Background: Despite there being a relatively large number of methods papers which detail specifically the development of stimulation devices, only a small number of reports involve the application of these devices in freely moving animals. To date multiple preclinical neural stimulators have been designed and described but have failed to make an impact on the methods employed by the majority of laboratories studying DBS. Thus, the overwhelming majority of DBS studies are still performed by tethering the subject to an external stimulator. We believe that the low adoption rate of previously described methods is a result of the complexity of replicating and implementing these methods.
New method: Here were describe both the design and procurement of a simple and inexpensive stimulator designed to be compatible with commonly used, commercially available electrodes (Plastics 1).
Results: This system is initially programmable in frequency, pulsewidth and current amplitude, and delivers biphasic, charge-balanced output to two independent electrodes.
Comparison with existing method(s): It is easy to implement requiring neither subcutaneous implantation nor custom-made electrodes and has been optimized for either direct mounting to the head or for use with rodent jackets.
Conclusions: This device is inexpensive and universally accessible, facilitating high throughput, low cost, long-term rodent deep brain stimulation experiments.

1. Introduction

Several publications have reported the development and use of rodent stimulators for use in preclinical research (de Haas et al., 2012; Ewing et al., 2013; Forni et al., 2012; Harnack et al., 2008; Millard and Shepherd, 2007; Winter et al., 1998). Unfortunately, the description of these devices rarely contains sufficient detail to enable the faithful replication of them in independent laboratories. The detail necessary to reproduce such electronic designs requires (i) an accurate and complete circuit diagram, (ii) the PCB (printed circuit board) artwork, (iii) a complete BOM (bill of materials), (iv) placement plan and (v), in designs incorporating microprocessors, the firmware to control the microprocessor. Given such details, an individual with experience in electronics would be expected to succeed in replicating the design. In this contribution, we provide a full and detailed description of the design as well as all details necessary for the full procurement procedure and the subsequent final assembly of a simple microstimulator sufficient for many preclinical DBS applications. Further, we provide the necessary files (PCB, BOM and placement plan) necessary to obtain fully populated PCBs from an international supplier when transmitted to the fabrication house (Beta LAYOUT). The device is designed to be simple and inexpensive, reproducible without specialist skills, compatible with commonly used, commercially available electrodes (Plastics

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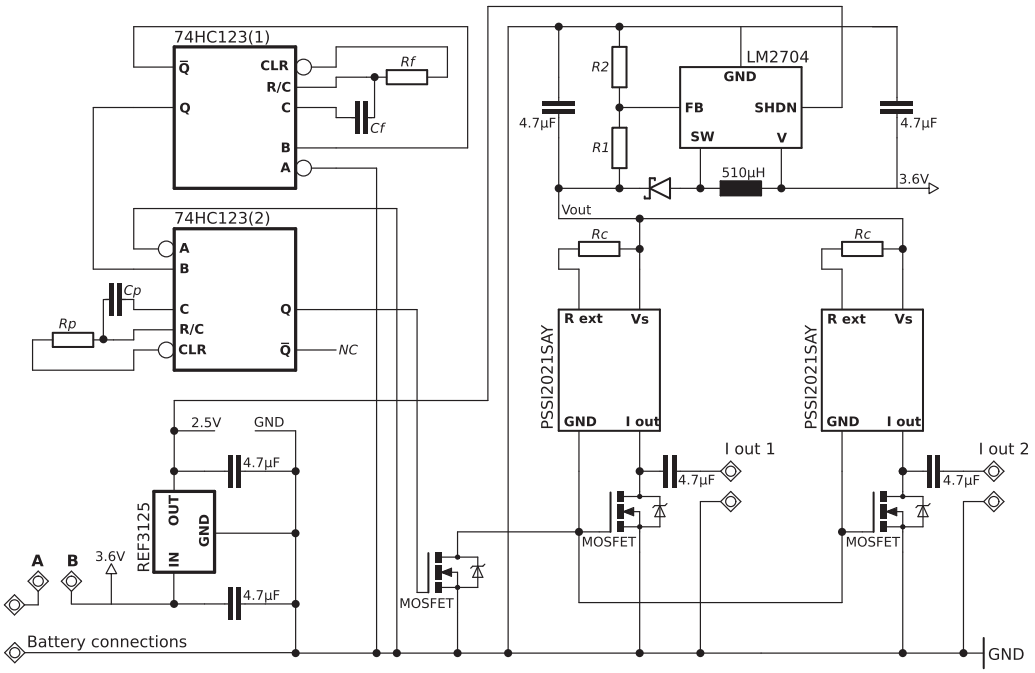

Fig. 1. Circuit diagram of the DBS device. NC indicates no connection. LM2704, charge pump; 74HC123, dual monostable multivibrator; PSSI2021SAY, constant current source. Shorting contacts A and B completes the power path switching the device on in design A (see Section 2.3.1). In design B a dedicated switch is installed between these points (see Section 2.3.2).

1) and easy to use. What this approach lacks in sophistication it gains in simplicity, ease of reproduction, ease of implementation and cost. It is our belief that the majority of preclincal DBS research labs are likely to be interested in testing only a single set of specific stimulation parameters in any subject and that these parameters are determined in the experimental design stage. Thus the ability to adjust the stimulation parameters midway through an experiment may be unnecessary. Finally we believe that these laboratories will be interested in stimulation periods of no more than 2–3 weeks. The final device design is tempered by these reasonable limitations in order to achieve maximum efficiency at the lowest cost.

2. Materials and methods

2.1. Circuit design

The stimulation circuit comprises three sub-assemblies: (i) pulse generator, (ii) two (bilateral) current sources and (iii) DC–DC voltage converter. These circuits are switched via high speed MOSFET switching transistors and the output is charge balanced via capacitive coupling of the electrode output and shorting to ground inbetween pulses (Fig. 1).

2.1.1. Power supply

Lithium thionyl chloride batteries provide high energy densities with extremely low self-discharge (less than 1% per year). The EVE EF651625 (Farnell Part No: 1973589) measuring 20.1 mm × 16.8 mm ×6.8 mm and weighing only 6 g provides an impressive battery capacity of 550 mAh. Both design A and design B are designed to surmount this battery although for devices intended for use with rodent jackets design B may be powered by the larger (25.8 mm × 16.8 mm × 7.0 mm, 8 g) EVE EF651625 battery (Farnell Part No: 1973588) which has a capacity of 750mAh. In design A the power supply is switched on and off by shorting a break in the power supply path (see Section 2.3.1). Design B has a dedicated on/off switch installed (see Section 2.3.2)).

2.1.2. Supply bypassing and regulation

The battery delivers a stable voltage of 3.6 V when discharged at a constant rate. However, the DC–DC converter causes unusually large voltage fluctuations. Voltage ripple on power supply lines causes errors in timing in the pulse generator. Thus, the power supply for the pulse generator must be very well regulated. The operating voltage for the pulse generator may be selected between 2 and 6 V. The MOSFET switches switch at a threshold of 2 V so a low power 2.5 V voltage regulator (Texas Instruments, REF3125, Farnell Part No: 1180185) is used to regulate the supply to the pulse generator. Minimizing the voltage supply in the pulse generator circuit minimizes the current draw in this subcircuit. Both the voltage regulator and the pulse-generator are then further bypassed with 4.7 µF capacitors.

2.1.3. Pulse generator

Stimulation pulses are generated using a dual retriggerable monostable multivibrator (Texas Instruments 74HC123, Farnell Part No: 1601156). These can be wired as a pulse generator with independent frequency and duty cycle control. The output is a square wave with a frequency defined by the resistor-capacitor network connected to the first monostable multivibrator (Eq. (1)) and a pulse-width defined by the resistor-capacitor network connected to the second monostable multivibrator (Eq. (2)). The frequency (F) generated at the output of the first monostable multivibrator (Q1) is determined by the values of R_f and C_f which may be selected using Eq. (1).

$$F = \frac{1}{K\ R_f C_f} \Rightarrow R_f = \frac{1}{KFC_f} \quad (1)$$

K varies as a function of supply voltage: $K = 0.46$ for $V_{CC} = 2.5$. The pulse-width (P) is a function of the duty cycle and is determined by the the values of R_p and C_p which may be selected using Eq. (2).

$$\text{Duty cycle} = \frac{R_p C_p}{R_f C_f} \Rightarrow P = KR_p C_p \Rightarrow R_p = \frac{P}{KC_p} \quad (2)$$