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Implementation of a galvanically isolated low-noise power supply board for multi-channel headstage preamplifiers

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Abstract

Custom made multi-channel headstage preamplifiers are traditionally powered by battery. By the use of an isolated unregulated DC/DC converter integrated circuit (DCP010512B from Texas Instruments Inc., TX, USA), here we describe the implementation of a galvanically isolated low-noise power supply board for multi-channel headstage preamplifiers. The implemented galvanically isolated power supply board provides the same quality noise free recording as the battery power supply. The non-isolated part of the power supply board is powered by standard 230 V AC/6 V DC wall mount adapter or USB cable. The described galvanically isolated power supply board can replace the batteries in preamplifier power supplies without any deterioration of the quality of recordings.

Keywords: Multi-electrode; Multiple single unit; Multi-site recording; Ensemble; Extracellular; Rat; Tetrode

1. Introduction

Increasing number of laboratories are interested in multi-channel electrophysiological recordings as many basic questions in neuroscience can only be answered by measuring neuronal activity in relation to behavior. Despite the significant methodological progress in multi-channel recording technique in the last decade, the effective application of the technique still represents a great challenge for system neuroscientist (Buzsaki, 2004; Foster and Wilson, 2006; Hafting et al., 2005; Harris et al., 2002; Leutgeb et al., 2005; Sargolini et al., 2006). In the last couple of years, several simple and practical solutions (Cham et al., 2005; Gray et al., 2007; Jeantet and Cho, 2003; Jurgens and Hage, 2006; Keating and Gerstein, 2002; Korshunov, 2006; Korshunov and Averkin, 2007; Lansink et al., 2007; Mathe et al., 2007; Musial et al., 2002; Swadlow et al., 2005; Szabo et al., 2001a,b, 2002; Venkatachalam et al., 1999; Venkateswaran et al., 2005), as well as free software (Hazan et al., 2006) have been described to ease the technical challenge. These can reduce the significant investment typically required by the laboratories to introduce the multi-channel recording technique.

A common problem in multi-channel multiple unit recording electrophysiological experiments on freely moving animals is the use of the proper power supply. It is critical because in these experiments the high impedance electrodes are collecting various ambient electric noises from the electromagnetic environment of the laboratory. Major part of ambient electric noise is coming from the 115/230 V main electric circuit and it can infiltrate the recording with high amplitude. A carefully designed Faraday shielding can reduce the noise but the real solution is the use of the unity-gain FET preamplifier integrated circuits (ICs) close to the recording electrodes, at the experimental animals head (headstage preamplifiers). These preamplifiers are typically powered by galvanically isolated power supplies. The

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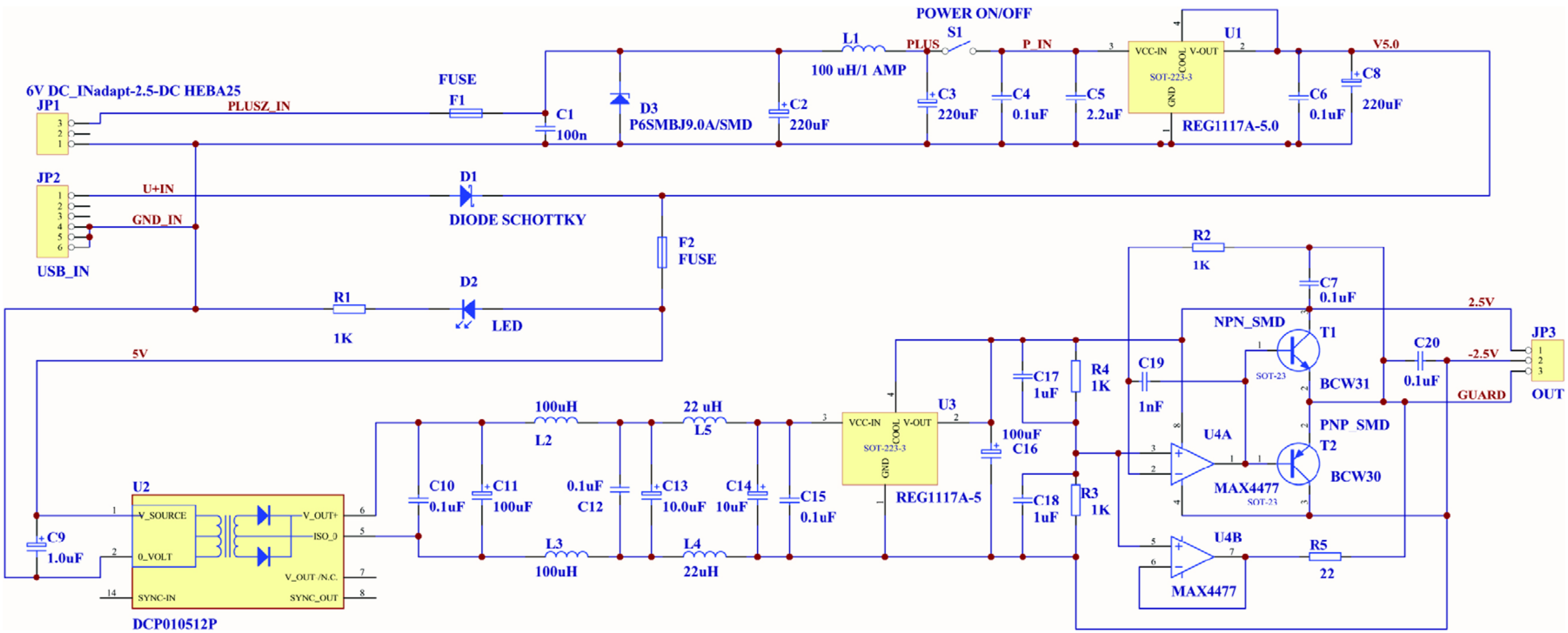

Fig. 1. Schematic drawing of the galvanically isolated low-noise power supply board. The most important component of the power supply board is 1 watt (W) isolated, unregulated DC/DC converter integrated circuit—DCP010512B. JP1 and JP2 are the input side where 230 V AC/6 V DC wall mount adapter or USB 5 V DC power can be connected. JP3 is the output of the galvanically isolated low-noise power supply where the ±2.5 V DC is presented.

most common galvanic isolation is the battery (Buzsaki et al., 1989).

The use of the batteries or rechargeable batteries, on the other hand, requires extra care as the batteries loosing the proper charge can induce strange electronic behavior in the preamplifier ICs before the complete loss of functioning. This strange electronic behavior as well as the loss of functioning of the preamplifiers in the middle of the experimental session will disturb the recording and screw up the experiments.

Here, we describe an additional small practical solution regarding the power supply of the multi-channel headstage preamplifiers: the implementation of a galvanically isolated low-noise power supply board by the use of an isolated unregulated DC/DC converter integrated circuit. The described low-noise power supply board can be used in multi-channel multiple unit experiments without the problem of interfering ambient noise.

2. Methods

The most important component of the galvanically isolated low-noise power supply board is the miniature, 1 watt (W) isolated, unregulated DC/DC converter integrated circuit (DCP010512B from Texas Instruments Inc., TX, USA; see U2 in Fig. 1; see also http://focus.ti.com/lit/ds/symlink/dcp010512b.pdf). It offers up to 1 W of unregulated 12 volt (V) output power with a typical efficiency of up to 85%. Its typical non-isolated input voltage is 5 V DC and its isolated output voltage is 12 V. The isolation between the 5 V input and the 12 V output is 1 kVrms and the barrier capacitance between the input and output sides is 5.1 pF. This extreme low capacitance (lower than the capacitance of the battery pack) makes the integrated circuit (IC) capable of powering the headstage preamplifiers contrary to common DC power supplies or other DC/DC converter modules. An additional advantageous feature of this IC is that it uses a push–pull, center-tapped topology switching at 400 kHz. This relatively high switching frequency allows a simple output filtering of the 20 mVpp ripple voltage. This switching noise could be easily reduced to the microvolt level with passive and active filtering.

At the input side of the circuit drawing (see Fig. 1) there is a terminal block JP1 where 230 V AC/6 V DC (or 115 V AC/6 V DC) wall mount adapter or other DC power supply will be connected. The requirement is that the DC voltage should be at least 6 V and cannot exceed 15 V DC. The incoming DC input after proper filtering (C1. . .C5 and L1) reaches REG1117A-5, a low-noise voltage regulator IC producing fix 5 V output voltage, that is the required non-isolated input voltage for the DC/DC converter IC (DCP010512B).

There is also an optional DC socket (JP2), a USB ‘B’ socket, that can receive 5 V DC power input from a PC through USB cable (see Fig. 1).

This way, the 5 V DC input to the DCP010512B DC/DC converter IC (U2) can come from one of two sources. There is a SCHOTTKY diode (D1) to protect the IC in the unfortunate situation when both the USB’s stabilized 5 V DC source and the other DC source are connected to the power supply board simultaneously. F1 and F2 are re-settable (“self-regenerating”) fuses (see http://www.bourns.com/pdfs/bourns_lead_free_pptc.pdf). D3 is a Zener diode that limits the input voltage to the U1 voltage regulator IC. It keeps the voltage at no more then 9 V and prevents against damages in the unfortunate case when the power is applied in reverse polarity to JP1.

As it was mentioned before, the DC/DC converter IC (DCP010512B) has 12 V output voltage and, in our case, this should be reduced to ±2.5 V. To this end, the 400 kHz ripple voltage first filtered by inductors (L2, L3, L4, L5) and capacitors (C10. . .C15), then the REG1117A-5 (U3) voltage stabilizer creates 5 V DC, galvanically isolated. In the next step, this 5 V DC is divided into the ±2.5 V DC by operational amplifiers (U4A and U4B) and transistors (T1 and T2). This ±2.5 V DC is presented at JP3 (see Fig. 1) as the output of the galvanically isolated low-noise power supply.

We used these output voltages because of our headstage preamplifiers (http://users.atw.hu/braintelemeter/preamplifiers.html). If different, e.g. higher isolated output voltage is needed then different voltage stabilizer IC (U3) can be used with the properly changed operational amplifiers (U4A and U4B). Furthermore, if necessary, the DC/DC converter IC (U2) can be changed to different version with higher output voltage or dual-voltage from the same Texas Instrument’s DC/DC converter IC family (see http://focus.ti.com/lit/ds/symlink/dcp010512b.pdf).

An assembled galvanically isolated low-noise power supply board is seen in Fig. 2. For more technical details, free Gerber files or PCB kit write an e-mail to szaboimre@yahoo.com.

3. Results and discussion

The performance of the isolated power supply board was tested primarily by an electrophysiological signal generator (Mathe et al., 2007), since its use is straightforward and it imitates the situation when neuronal discharges are recorded through the microelectrodes from the brain. It means the connec-

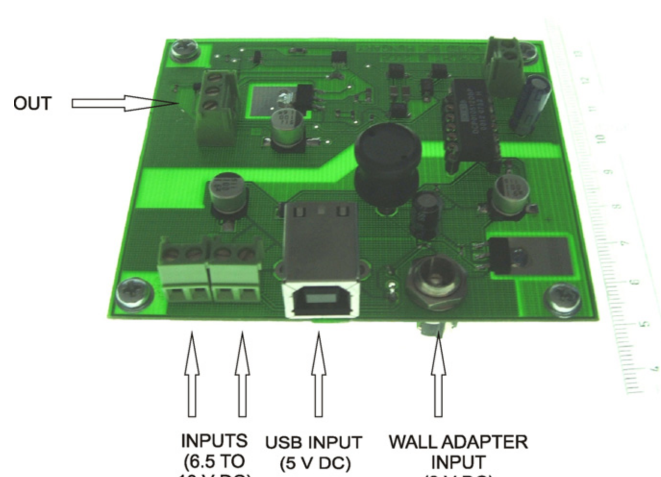

Fig. 2. Photo of the power supply board. Screws and sockets on bottom part are the different non-isolated input choices: DC power supply (6.5–10 V DC, JP1), USB (5 V DC, JP2) and wall adapter (9 V DC, JP1). Screws on the top left side: the terminal block (output, JP3) of the galvanically isolated (floating) power supply. Screws are +2.5 V, ground and −2.5 V.

tion of the signal generator, instead of the experimental subjects' electrodes, to the preamplifier. Monitoring is done in the same way as during recording from the brain. In Fig. 3A 50 μV signals were presented by the electrophysiological signal generator through 420 kΩ output impedances. This impedance corresponds to the impedance of microwire electrodes of multiple unit experiments. Recording was made with PREAMP-32LP (Noted Bt., Pécs, Hungary) in an unshielded room. The power supply of PREAMP-32LP was three rechargeable 1.2 V NI-MH batteries. The output signals from the unity-gain preamp were passed through a high performance biological amplifier (CyberAmp 380, Axon Instruments, USA), then to a 12-bit analogue–digital conversion interface (Micro 1401, CED, Cambridge, UK), and were stored and archived on IBM PC compatible microcomputer. The signals were visualized on-line by Spike2 software (CED, Cambridge, UK).

In Fig. 3B the record was made in the same way as in Fig. 3A but the power supply to the PREAMP-32LP was the galvanically isolated power supply board. Note that the recordings were indistinguishable from each other. The non-isolated part of the power supply board was a 230 V AC/6 V DC wall mount adapter.

The same kind of recording was made in the same quality (recordings not shown) when the non-isolated part of the isolated power supply board was power supplied by a USB cable from the PC.

As it was illustrated on the Fig. 3, the same noise free recording was achieved independently from the way the unity-gain preamplifier was power supplied—the power supply could be the battery or the galvanically isolated low-noise power supply board. The result is also independent from the way the non-isolated side of the galvanically isolated power supply board is

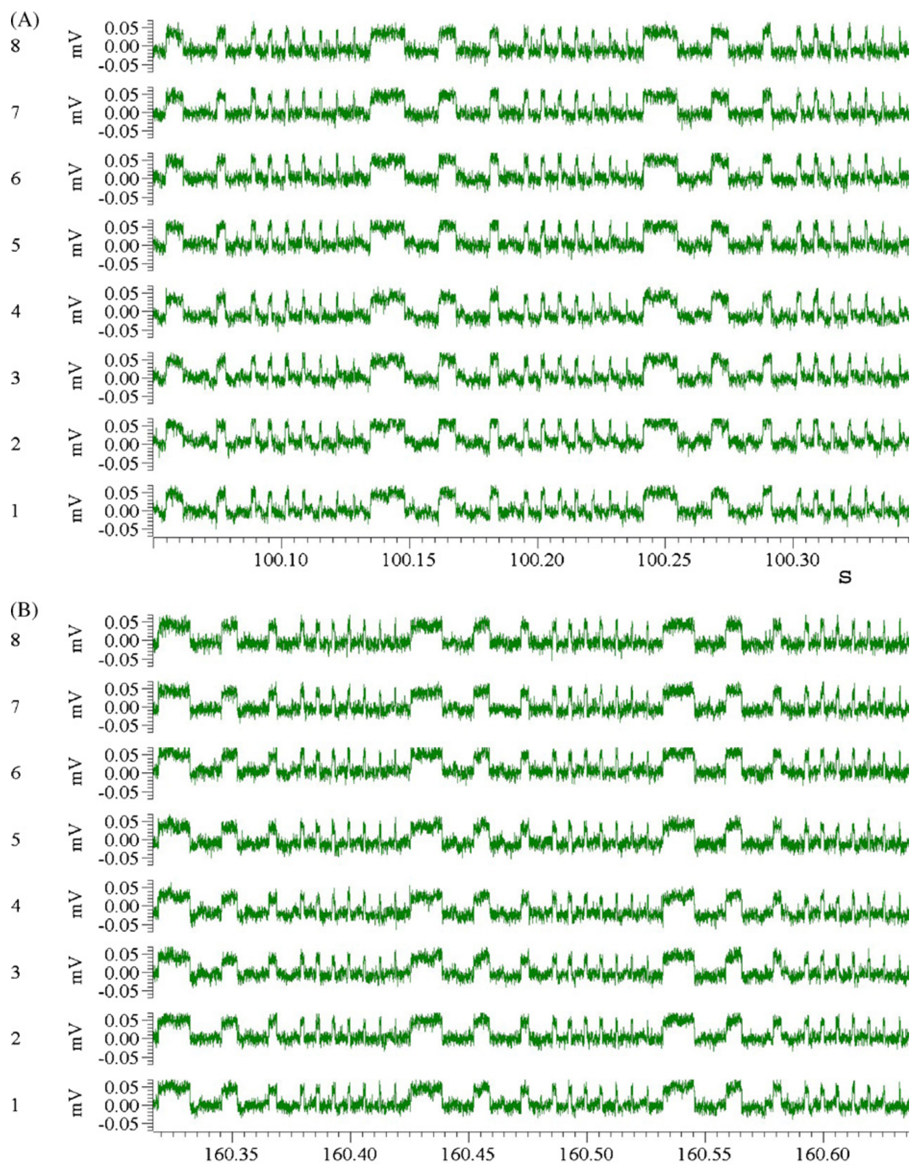

Fig. 3. (A) Fifty microvolts testing signals when the preamplifier's power supply is NI-MH rechargeable battery. (B) Same as (A) but the preamplifier's power supply is the galvanically isolated power supply board powered by 230 V AC/6 V DC wall mount adapter.

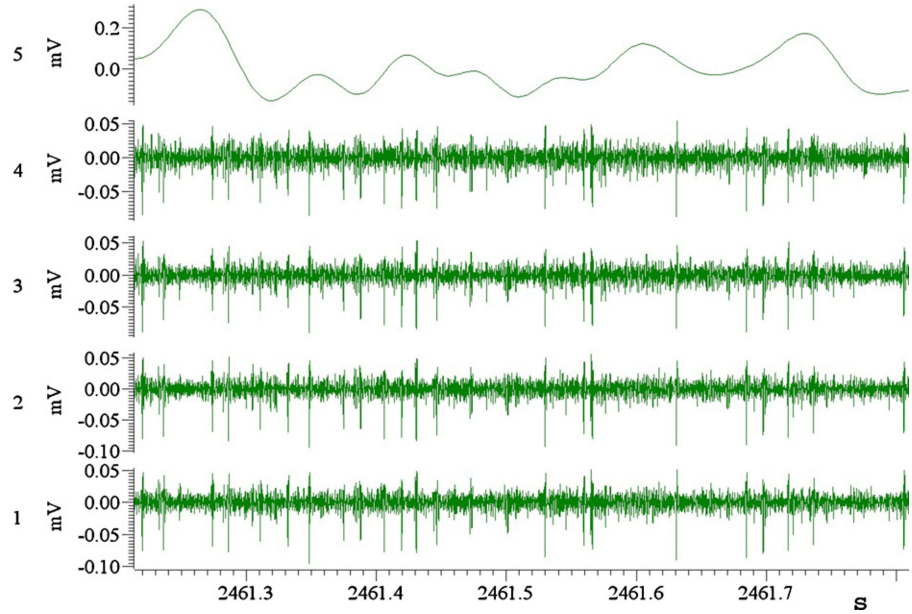

Fig. 4. Recording was made from a single tetrode that was chronically implanted into the left medial prefrontal cortex of the rat. Channel #5 is the same as channel #1, but filtered for EEG. The channels of the recording were amplified (20 k) and digitally filtered for multiple unit display (600 Hz, high-pass, 4 kHz low-pass) and field potential (2 Hz, high-pass, 220 Hz low-pass).

powered—it could be 230 V AC/6 V DC wall mount adapter, or the USB port of a PC.

Recording shown in Fig. 4 is obtained from a rat, chronically implanted with wire tetrode electrodes. Wire tetrodes were constructed from four 25 μm H-ML insulated Ni–Cr wires (Stablohm 675, California Fine Wire, CA, USA) bound together by twisting. After gold plating the electrode impedance ranged between 100 and 250 kΩ. The position of the tetrode was adjusted by a PCB microdrive (Szabo et al., 2001a; Toth et al., 2007) to record multiple unit discharges from the left prefrontal cortex. In the first four channels the record was filtered (600 Hz, high-pass, 4 kHz low-pass) for multiple unit display. In the 5th channel the filters of the main amplifier were set for EEG frequency range. Channel #1 and channel #5 in Fig. 4 was recorded from the same wire. The non-isolated part of the isolated power supply board received 6 V DC from a wall mount adapter (230 V AC/6 V DC).

Our test recordings were shown, that the galvanically isolated low-noise power supply board made by the use of Miniature, 1 W Isolated Unregulated DC/DC converter IC (DCP010512B from Texas Instruments Inc., TX, USA) provide the same kind of noise free recoding as the battery power supply. Therefore, this power supply can substitute for the use of batteries to power on-subject buffering preamplifiers in electrophysiological applications. The use of this power supply can be especially advantageous for long recordings, e.g. in animal models of epilepsy research, where recordings can last days or weeks.

There are two further advantages of using an isolated power supply over batteries or non-isolated power supply of a commercial recording system. (i) If the supply is powering opamps, then the opamp can pass current into the tissue, producing a lesion if the positive and negative supply voltages become unbalanced. This is more likely to occur with batteries than with the described power supply. (ii) For applications that require shocking the animal during recordings, a supply that is not isolated will provide a low impedance path for the shock current through the ground of the preamplifier. Since this is either an electrode in the brain or a screw in the skull, the shock will travel though the head, which is unwanted. The isolated supply makes such shocking applications possible.

In summary, the galvanically isolated power supply board can replace batteries in preamp power supply without any deterioration in the quality of the recordings.

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