Design and Development of a Wireless Infrared EEG Recorder

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Abstract— **In the field of sleep studies, a major unanswered question concerns the development emergence of cycles of sleep and waking during embryonic life. In this regard, useful insights can be provide by the correlation of Electroencephalography (EEG) signals with brain metabolic activity, collected by means of Positron Emission Tomography (PET). Hence, a telemetric system for the recording of chicken embryo EEG signals electromagnetically compatible with a PET scan machine has been developed. To avoid electromagnetic interference, the system developed in this work is based on an infrared data link. The system is composed by a small low power IR transmitter which sends sampled data to a receiver which is connected to a PC for signal processing and data storage. The transmitter collects EEG/EMG data from 6 channels, with a sampling frequency of 200 Hz and an accuracy of 12-bits. The transmission range is up to 30 cm approximately, compatible with the required application. The proposed transmitter total size is 13x16 mm, excluding the battery.**

Keywords— EEG, Telemetry, Infrared communication, Embryo

I. INTRODUCTION

The measurement of bio-potential signals, such as brain potentials, is a mainstay of biomedical research. Particularly, the developmental origins of cycles of sleep and waking in higher vertebrate animals (birds and mammals) are currently unknown. The correlation of the EEG signals with brain metabolic activity, measured with Positron Emission Tomography (PET) may provide a useful approach to the question of the generation of the EEG signals. Birds (in our case, chickens) can be used as model animals for these studies, for many practical reasons related to the accessibility of their embryos[1-2].

In these experiments, the use of a wireless apparatus is of paramount importance for allowing an easy setup of the data collection system, especially when many different measurements must be collected at the same time in a constrained space. Many wireless systems are in fact presented in literature, most of which based on radiofrequency communication [3-6].

A telemetry system, composed by a transmitter and a receiver that used an IR link for communication, has been developed. The infrared data link was chosen for the communication to avoid electromagnetic interference between the EEG system developed in this work and the PET scan machine.

Infrared (IR) communication technologies are widely used. Most remote controls of many common household devices are in fact based on it. The main disadvantage of infrared transmission is the limit range and the low energy efficiency of the link between the transmitter and the receiver [7]. Furthermore IR data links require an uninterrupted light path between the IR emitter diode the receiver photodiode. However, infrared technology can provide several advantages in biomedical applications [1,8]. In contrast to RF transmission, for example, the infrared signal can easily be confined in a limited space, avoiding interferences with other systems; more important, IR communication is less susceptible to interference from other nearby devices. It can be implemented simply and its costs are small. Based on these advantages, we have chosen to use the wireless signal transmission for the system developed.

This paper is organized in the following sections: Section II) describes global architecture the system; Section III) describes in detail the transmitter and the IR link; Section IV) describes the receiver and the link with the computer employed for data storage; and finally (Section V) discusses the system performance.

II. SYSTEM OVERVIEW

A. System specification

The system developed in this work was designed for the real-time acquisition of EEG and EMG signals from in *ovo* chicken embryos and their storage on a PC for subsequent

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analysis. The system is composed by a transmitter and a receiver which communicate through an infrared data link.

The transmitter is based on a small low power battery-powered system attached to the outside of the incubating egg. The circuit is connected by means of thin metal wire electrodes, which enter the egg through a hole in the shell and are surgically implanted on the surface of the embryo brain. The system employs 7 electrodes which provide 6 EEG/EMG data channels (the 7th electrodes is used a common reference). The system is designed to do a continuous acquisition of a few days with AA alkaline batteries. The IR emitted signal is collected by a photodiode installed nearby and fed to the receiver. The signal is amplified, conditioned, and decoded. The data stream is then processed by a microcontroller, which formats and forwards the data to the PC with either a USB link or a standard RS-232 link.

The EEG signal has typical amplitude of 1 to 100uV and a typical bandwidth from 0.1 to 60Hz [9]. We assumed an upper frequency limit of 100Hz, because the EMG signal have a slightly larger bandwidth requirement. For this reason, we used a sampling frequency of 200Hz.

B. Transmitter

The transmitter requires a supply voltage of 3V and is battery operated. It is composed of a signal conditioning front-end, that remove the DC voltage present at the input, amplifies the signal and acts as anti-aliasing filter, imposing the upper cut-off frequency. The signal is sampled with a 6 channel 16 bit ADC, and is fed to a microcontroller (Atmel Attiny88) through SPI communication. The microcontroller format the EEG data into packets, adding additional information like temperature, battery voltage, serial number and a checksum byte. The packets are encoded with the bi-phase mark-coding scheme (BMC, IEEE 802.5, ISO/IEC 7811). Finally, the processor sends the encoded packet stream from the SPI port to the power amplifier and the IR emitting diode.

The transmitter PCB layout and AVR firmware have been optimized to reduce its size, weight and power consumption.

C. Receiver

The receiver signal is received by a photodiode, pre-amplified and amplitude limited by an automatic gain control loop. The amplified signal is conditioned and then digitalized. Finally, the digital signal is fed to a microprocessor which implements the BMC decoding and reformats the packets, checking the data integrity, and sends the data to the PC with a USB link. The PC software displays the data, the transmitter temperature, the battery voltage and the serial number, and saves the data to file for subsequent analysis.

III. TRANSMITTER

The transmitter block-diagram is showed in Fig. 1. The transmitter is battery-operated and it is composed by 8 operational amplifiers in 2 quad packages (6 op-amps are used for the six channels, one generates a reference voltage and one is not used), a 16-bit ADC, a microcontroller, a bipolar transistor and an IR emitting diode.

The transmitter collects 6 EEG/EMG channels 6 electrodes connected to the embryo brain surface. The reference voltage (equal to ½ of the battery voltage) is generated with a voltage divider and a op-amp buffer and is applied to the brain with an additional reference electrode. Each channel is amplified and band limited by a single operational amplifier in quad package (Linear Technologies LTC6078) mounted in the non-inverting configuration. The amplified signals are then sampled by an eight channel ADC converter (Analog Devices AD7689) where only six channel are used, with a sampling frequency of 200 Hz and with a resolution of 16 bits; since the dynamic range of the EEG signal is about 60 dB (10 bits), only 12 bits of each sample are selected and transmitted, saving bandwidth. The ADC is connected with an SPI (Serial Peripheral Interface) communication link to a microcontroller (Atmel ATtiny88).

The processor encodes the data stream with the bi-phase mark-coding scheme (BMC) with a data rate of 62.5 kbit/s. The samples are formatted in packets of 128 bits, which contain, besides the 6 12-bit samples, values of the system temperature (taken from the microcontroller on-chip temperature sensor), the battery voltage, a sequential number and a checksum. The time for the transmission of each packet is about 2ms and is follower by a 3ms pause before the transmission of the next packet.

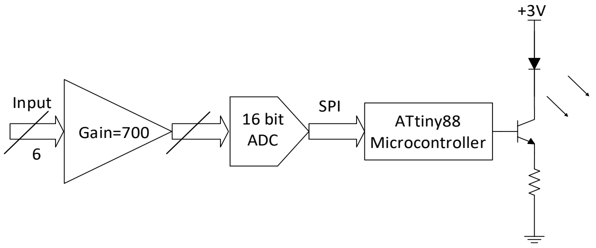

Fig. 1. Block diagram of the infrared transmitter

The firmware was written using C with some subroutines in assembly code to have a better efficiency. The data is BMC encoded with an hybrid software-hardware approach: each block of 4 bit is encoded with a lookup table and serialized with the SPI shift register. The output of the SPI port is routed to the power amplifier transistor and the amplified current (50 mA peak) is applied to the IR emitting diode, which has an emitting angle of 120°. The average current consumption of the complete transmitter is about 10 mA. The size of the transmitter PCB is 21x14 mm.

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IV. RECEIVER

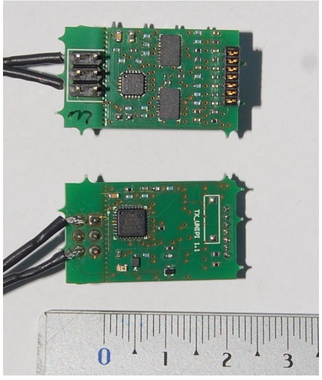

Fig. 3. Photo of the designed transmitter. On top layer (above in the photo) are visible the two quad op-amps, the ADC and the programming connector, which can be broken off after software download to reduce size. On bottom layer (below in the photo) are the processor and the IR transmitting diode (small white square).

The receiver block-diagram is showed in Fig. 3. It is composed by an analog front-end and a digital back-end. The receiver amplifier chain is split in two separate PCB. The first PCB contains the photodiode (940nm) and the transimpedance amplifier (Burr-Brown OPA627). The second PCB contains an 10 dB fixed-gain amplifier (Analog Devices AD817), a variable gain amplifier (Analog Devices AD600) and an 80 MHz 32-bit ARM Cortex-M4 processor (Texas Instruments with a USB and a traditional RS-232 output. A SMA coaxial cable connects the first PCB to the second.

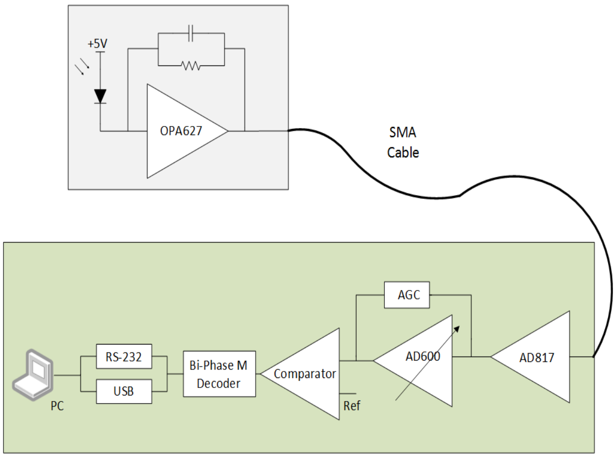

Fig. 2. Block diagram of the receiver. Transimpedance amplifier (above) and receiver back end (below).

The solution with two separate PCB for the receiver has been chosen to eliminate the crosstalk between the transimpedance amplifier and the other blocks. Furthermore, the small size of this PCB (33x38 mm) allows the best placement of the receiving photodiode in the limited space of the PET machine chamber (a cylindrical space with an 80 mm diameter).

The optical signal is received by an IR photodiode and amplified by a chain of three amplifiers, one in the first PCB and two in the second. The last amplifier is a variable gain amplifier controlled by the received mean signal amplitude and hence implements an automatic gain control loop. Then, the signal is conditioned and digitalized by a comparator. The digital signal is collected by Cortex-M4 processor, which retrieves the data stream from the BMC modulated signal, reformats the packets, and sends the data to the PC. The receiver is equipped with both an USB link and a standard RS-232 port. The packets sent to the PC include status system information (battery voltage and transmitter temperature), a 16-bit transmitter identification code and a checksum, to verify the data integrity.

Fig. 4 shows the communication between the transmitter and the receiver. Fig 4a shows two complete packets, and the Fig 4b shows a detailed view of the first bits of a packet. Each bit is 16 μs, leading, for 128 bits to a transmission time of 2.048 ms. The transmitter sends a new packet every 5 ms.

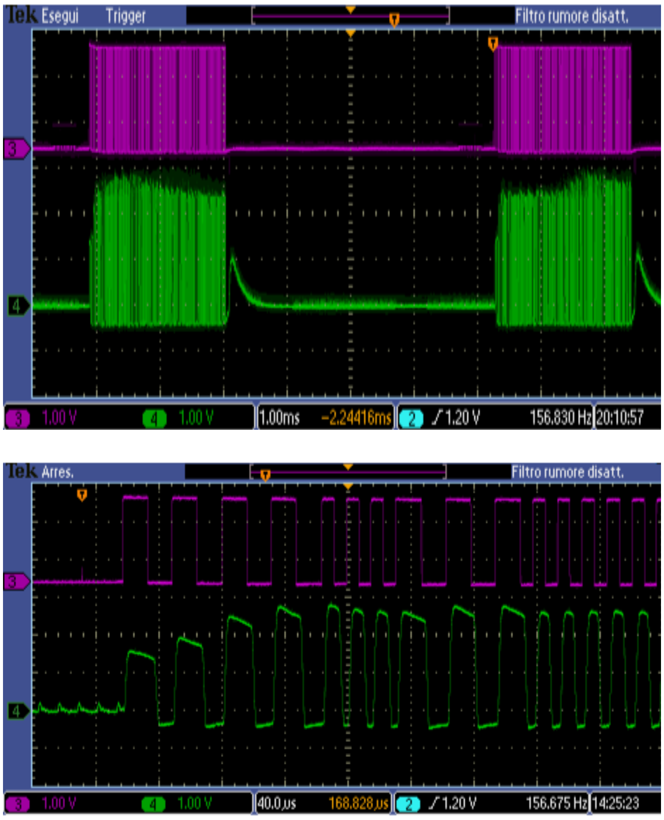

Fig. 4. Two complete transmitter and received packets (a, above) and a detailed view of a packet (b, below)

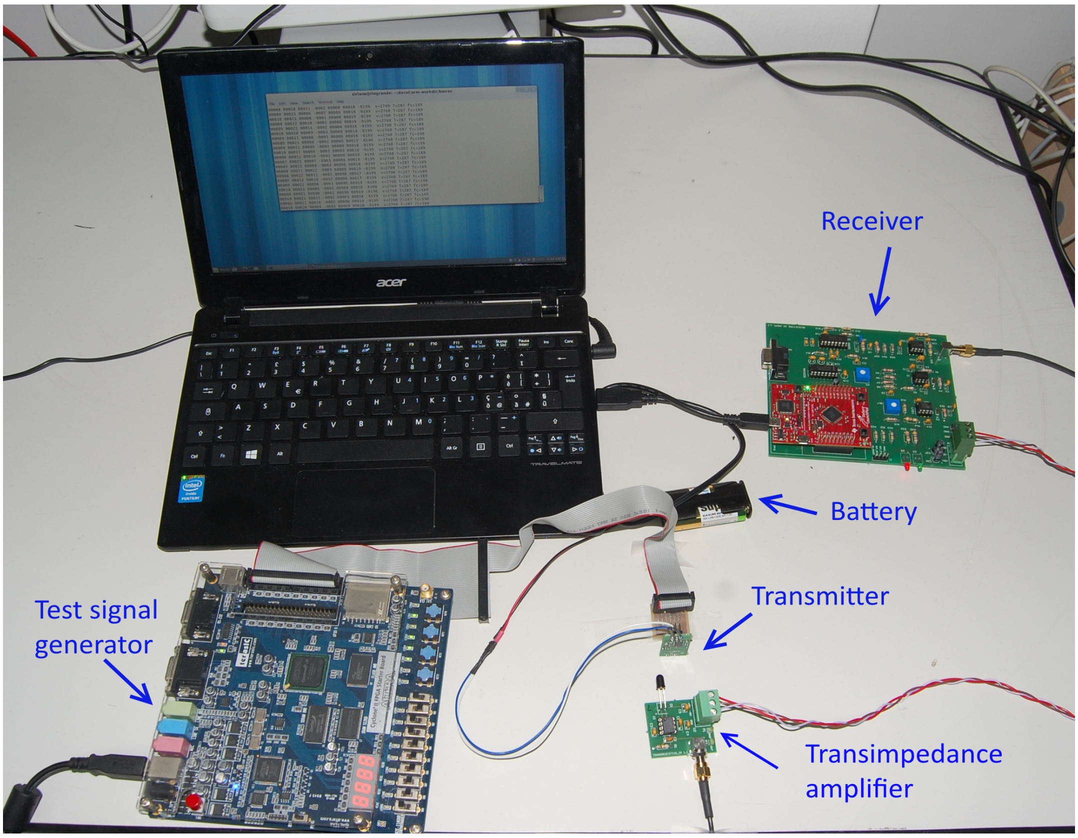

Fig. 5. The complete system under test with transmitter, receiver and the test signal generator

V. PERFORMANCE AND DISCUSSION

The complete system, composed by transmitter, receiver, connected to a test signal generator (based on an FPGA prototype board) is shown in Fig. 5.

The system was tested in laboratory using sinusoidal test signals at different frequency (0.5, 1, 3, 8, 20, 50 Hz, with an amplitude of 300 µV) in the typical band of EEG signals. The received data by USB port were saved in a PC e then was plotted as showed in Fig. 6. The received signals are filtered and analyzed in frequency domain to verify the received frequency. Other tests, performed without stimulus signal allowed to estimate the noise level of the system, which is about 1 µV.

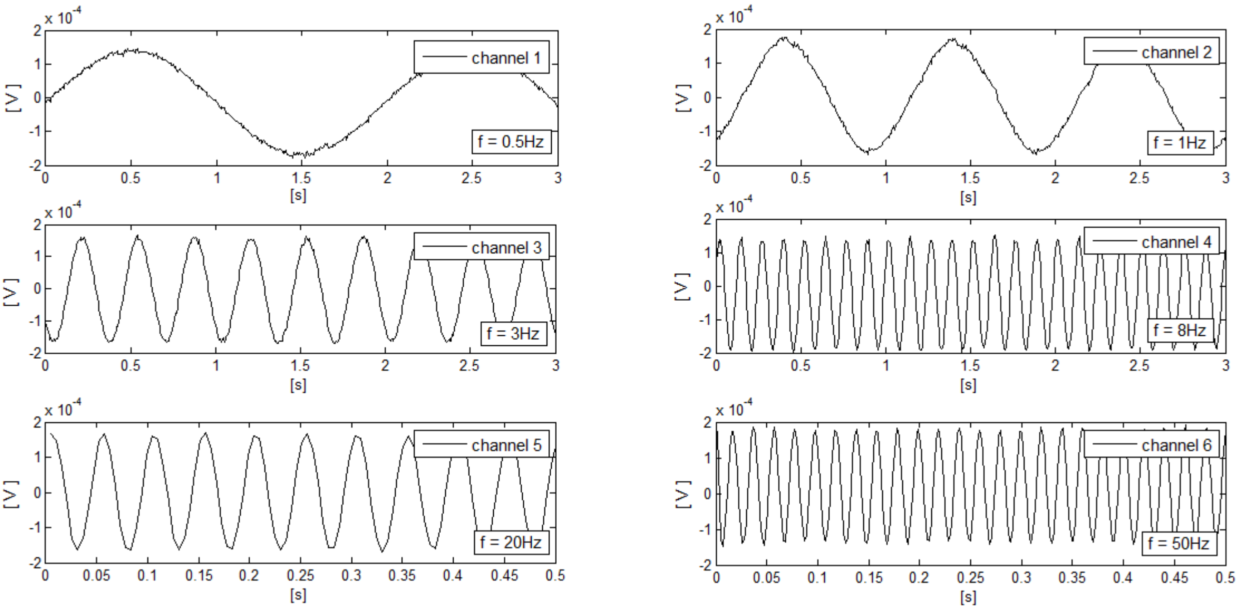

Fig. 6. Recorded signals with test sinusoid signals (300 µVpp at at 0.5, 1, 3, 8, 20 and 50 Hz).

VI. CONCLUSION

In this work we have designed a novel telemetric EEG/EMG recorder based on an IR link for the data transmission, electromagnetically compatible with a PET scan. All system components were designed, build and tested. The performance is compatible with the required application, and the system is fully working.

REFERENCES

[1] M.A.CornerandW.L.Bakhuis,"Developmental patterns in the central nervous system of birds v. cerebral electrical activity, forebrain function and behavior in the chick at the time of hatching." *Brain research*, vol. 13, pp. 541–555, 1969.

[2] V. A. R. Peters, J. J. and S. D., "Onset of cerebral electrical activity associated with behavioral sleep and attention in the developing chick." *Journal of experimental zoology*, vol. 160, pp. 255–262, 1965.

[3] R. A. Rashid, M. Rozaini, M. A. Sarijari, and N. Mahalin, " Design and Implementation of Wireless Biomedical Sensor Networks for ECG Home Health Monitoring," in 2008 International Conference on Electronic Design, Penang, Malaysia, Dec. 2008.

[4] C. N. Chien et al., " Microcontroller-based wireless recorder for biomedical signals," in Proc. IEEE Engineering in Medicine and Biology 27th Annual Conference, Shangai, China, Sep. 2005, pp. 5179–5181.

[5] Di Pascoli, S.; Puntin, D.; Pinciaroli, A.; Balaban, E.; Pompeiano, M., "Design and Implementation of a Wireless In-Ovo EEG/EMG Recorder," in Biomedical Circuits and Systems, IEEE Transactions on , vol.7, no.6, pp.832-840, Dec. 2013, doi: 10.1109/TBCAS.2013.2251343

[6] Lapray, J. Bergeler, E. Dupon, O. Thews, H. J. Luhmann "A novel miniature telemetric system for recording EEG activity in freely moving rats," J. Neurosci. Methods, vol. 168, no. 1, pp. 119–126, 2008.

[7] A. C. Metting van Rijn, A. Peper, C.A. Grimbergen "A wireless infrared link for a 16-channel EEG telemetry system," in Proc. International Conference of the IEEE Eng. in Medicine and Biology Soc., Baltimore, MD,USA 1994, pp. 906–907.

[8] W. Phanphaisarn, J. Koseeyaporn, P. Wardkein, "Low Cost Infrared Wireless ECG by Using a Simple Sigma-Delta Modulation," in Proc. Biomedical Circuits and Syst. Conf., 2006, pp. 245–248D.

[9] Paul L. Nunez, Ramesh Srinivasan, Electrical Fields in the brain, Oxford University Press, 2005.