A PORTABLE, DIFFERENTIAL AMPLIFIER FOR RECORDING HIGH FREQUENCY EEG SIGNALS AND EVOKED POTENTIALS

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***Abstract* – In a clinical context, EEG refers to recording the brain's spontaneous electric activity, using small electrodes placed on the scalp. The signals collected are electric "potentials" measured between two electrodes. Usually, for a healthy adult, these signals have small voltage (10µV to 100 µV) and frequencies in the 0-40 Hz range. In the scientific literature, there are mentioned EEG signals and evoked potentials that have higher frequencies (up to 600Hz) and amplitudes lower than 500nV. For this reason, building an amplifier capable of recording EEG signals in the nV range and with frequencies up to couple of kHz is necessary to continue research beyond 600 Hz. We designed a very low noise amplifier that is able to measure/record EEG signals in the nV range over a very large frequency bandwidth (0.09 Hz -385 kHz).**

***Keywords* – instrumentation amplifier, EEG signals, evoked potentials**

1. INTRODUCTION

EEG signals have been studied since 1924, when Hans Berger recorded the first EEG signal using silver electrodes and a galvanometer. Alpha waves (8-12) Hz were the first to be discovered. Due to mechanical limitations of the pen-writer EEG recording units, used until late 1980s, the clinical diagnostics based on EEG signals are related only to the low-end frequency spectrum, up to 30 - 40 Hz. The digital EEG made possible the recording of signals within a wider frequency range. In the last couple of years, the scientific literature mentions ripples during sleep at 80-200 Hz [1] and somatosensory evoked potentials (SEPs) having 600 Hz and amplitudes <500 nV [2]. Taking these recent results into account, we decided to conceive and to build an amplifier able to record EEG signals in the nV range over a lot wider frequency range.

2. THE INSTRUMENTATION AMPLIFIER

Our amplifier is an instrumentation amplifier with differential inputs [3]. The particularities of this circuit will be discussed in the following paragraphs. A block scheme of the amplifier is presented below (Fig. 1).

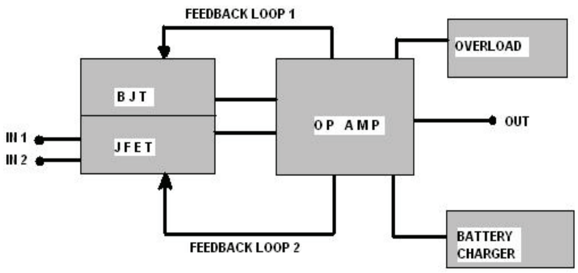

Fig. 1 – Block scheme of the amplifier

The amplifier is built in a small metal box, with SMA connectors on both inputs, a BNC connector for the output and two RCA connectors for the battery recharge circuit. (Fig. 2)

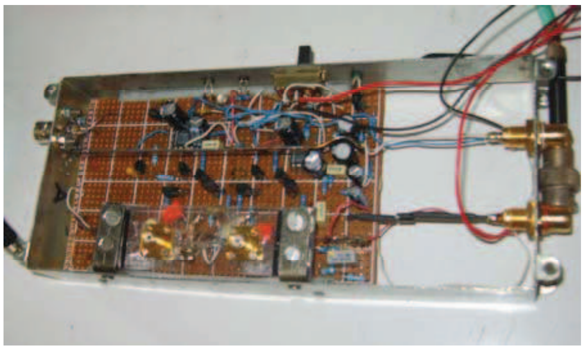

Fig. 2 – The amplifier prototype

2.1 First Gain Stage

For each input signal, a pair of cascades is used. The cascade consists of a JFET (2SK170) transistor and a BJT (BC550) transistor. As a result the input – output isolation is improved and the amplifier has a larger bandwidth. The input impedance is 10 MΩ per channel, 20 MΩ for a differential signal and 5 MΩ for the common mode signal. Two cascades in parallel for each input signal have a great impact on the noise level, which is lower than if only one cascade was used. As a drawback of using cascades, (having 4xJFETs and 4xBJTs used only for the input channels), is that the batteries which power the circuit must be recharged more often, as they drain faster. The static operation point of the four 2SK170 transistors are chosen in order to minimize the noise level through this gain stage. Therefore the drain current is set to $I_D = 4\ mA$ (Fig. 3) and the drain-source voltage is set to $U_{DS} = 6.6\ V$ (Fig. 4), which, according to the manufacturer's data sheet [4], ensures an equivalent input noise voltage with a value smaller than $1\ nV/\sqrt{Hz}$ (Fig. 5).

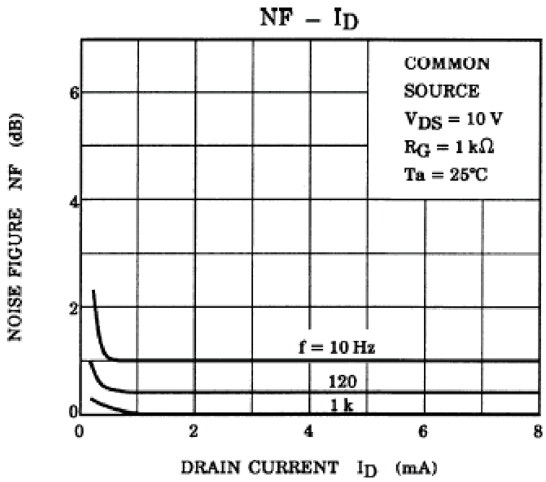

Fig. 3 – Noise figure for the 2SK170 transistor

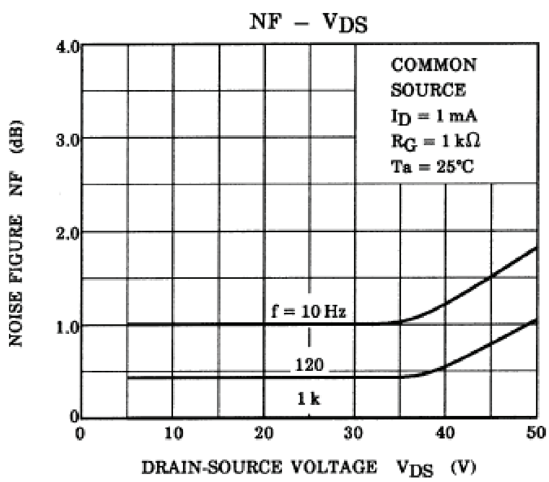

Fig. 4 – Noise figure for the 2SK170 transistor

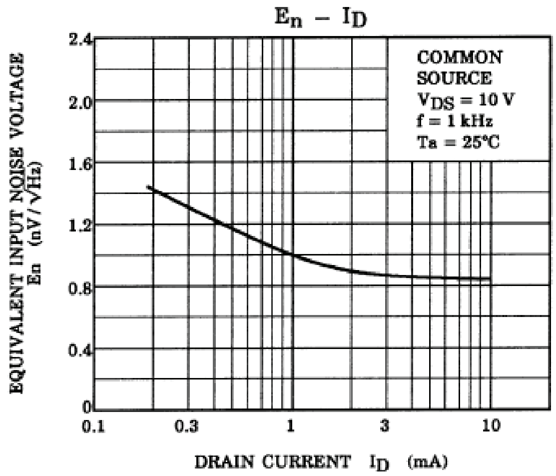

Fig. 5 – Equivalent input noise voltage for the 2SK170 transistor

2.2 Operational Amplifiers

High-end LT1028A operational amplifiers (op amps) are used in the feedback loops with the input stage of the amplifier. The voltage noise density of these op amps is as low as 0.85 $nV/\sqrt{Hz}$ at 1kHz and $1\ nV/\sqrt{Hz}$ at 10Hz [5] (Fig. 6). Two LT1028 are used into the circuit. Both of them are powered by a differential power supply, having 16.8V on the positive side and -8.4V on the negative side.

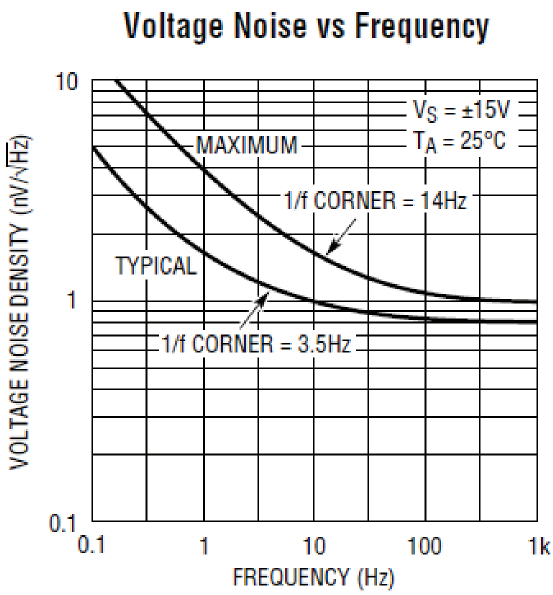

Fig. 6 – Voltage noise density versus frequency for the LT1028A op amp

2.3 Negative Reaction Loops

Two negative reaction loops are used in this circuit. One is used to realize an instrumentation amplifier. The output impedance of the amplifier is 50 Ω. The second loop is used to maintain a certain drain current value through the 2SK170 transistors.

2.4 Overload Protection

The amplifier is designed with overload protection against output signals with amplitudes higher than +/-1.2V. Two LEDs indicate whether the amplifier is overloaded on the positive or the negative side.

2.5 Battery Recharge Circuit

Using rechargeable batteries to power the amplifier is a great solution to avoid power line noise. Therefore, a small battery recharge circuit is added to the amplifier. A two-position switch can change between measuring mode and battery recharge mode. Both modes are totally independent of each other.

3. MEASUREMENTS AND RESULTS

3.1 Overall characteristics

Differential voltage gain: 36 dB

Gain bandwidth: 0.09 Hz - 385 kHz

Common mode rejection ratio: 95 dB

Differential input resistance: 20 MΩ

Output resistance: 50 Ω

Equivalent input noise voltage: $7\,nV\ /\ \sqrt{Hz}$

3.2 Gain and Bandwidth

The differential gain of the amplifier is 36 dB within 0.09 Hz - 385 kHz frequency range. (Fig. 7)

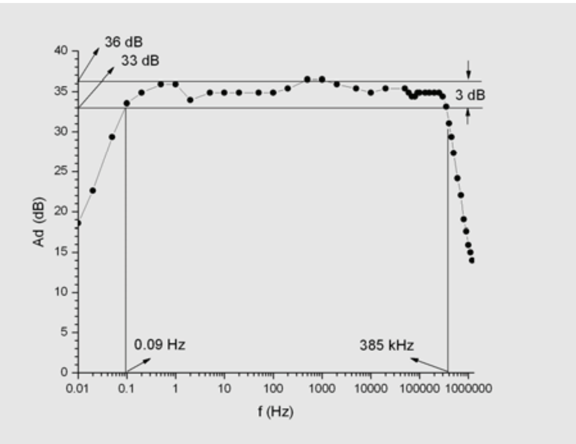

Fig. 7 – Amplifier voltage gain versus frequency

3.3 Noise Measurements Using Lock-In Amplifier

The internal noise of the amplifier has been measured using a Stanford Research SR530 Lock-In Amplifier. The 1/f corner is at 22Hz. The equivalent input noise voltage is $7nV/\sqrt{Hz}$ frequencies higher than 22 Hz (Fig. 8).

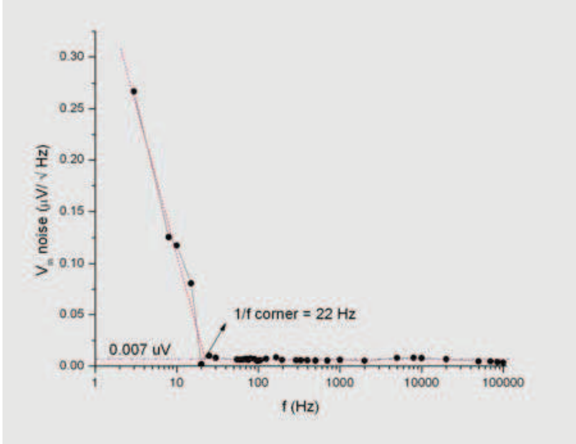

Fig. 8 – Equivalent input noise voltage of the amplifier versus frequency

3.4 Common mode rejection ratio

The common mode rejection ratio is one of the most important parameters of an instrumentation amplifier. During an EEG recording, where the signal is apparently random for a defined point on the scalp, but definitely different than any other signal recorded at a small distance around that point, it is important too reject signal components that are the same on both input channels. A common mode rejection ratio of 95dB has been reached (Fig. 9).

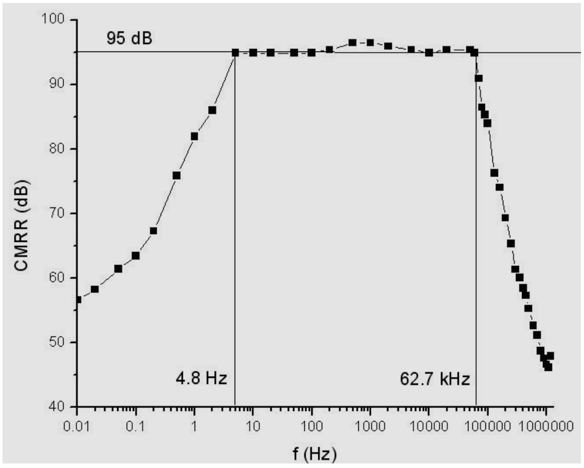

Fig. 9 – Common mode rejection ratio versus frequency

4. CONCLUSION

Looking at the characteristics of this amplifier, we can conclude that it is suitable for EEG signal recordings and evoked potentials too. With an input noise signal of $7nV/\sqrt{Hz}$, the amplifier is able to measure very small signals (in the nV range), which have frequencies in the 0.09 Hz – 385 kHz range. Also, the small dimensions, light weight and the battery power supply make the amplifier suitable for a wider range of applications (as emergency units, high school labs, etc).

5. REFERENCES

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