

Design of low-noise preamplifier for medical diagnostic system

R. Raišutis, O. Tumšys, V. Laurs

Ultrasound Institute, Kaunas University of Technology

Studentų 50, 51368 Kaunas, LITHUANIA,

Phone: +370 37 351162, Fax. +370 37 451489,

E-mail: ulab@ktu.lt.

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Abstract

Experimental investigation of the developed eye tumors diagnostic system has revealed the tasks of system improvement, like reduction of the noise level of the preamplifier. The reliable solution is selection of analogue components of the preamplifier possessing as low noise level as available in the market of electronic components supply. Simultaneously, well known techniques of noise reduction should be used during the process design also.

This paper discusses the design and development of the ultra-low noise preamplifier for medical applications. For the preamplifier schematic the principle of low frequency amplification with reduced the amplifier noise by \sqrt{n} , where n is the number of amplifiers, is proposed. Using the final design of the preamplifier the noise factor value of 0.46 dB with gain of 48 dB and bandwidth of 2-35 MHz has been achieved.

Keywords: eye tumors diagnostic system, low-noise preamplifier, signal to noise ratio, noise factor.

Introduction

In ultrasonic-based diagnostic medical imaging the principles of non-destructive testing are used to visualize internal organs and tissues of human body [1-5]. The ultrasonic transducer excited by a high voltage generator generates an ultrasonic beam over the region of investigation. The reflected ultrasonic signals are used to construct the image of this region. This principle is developed in ophthalmology to perform diagnosis of malignant tumors of the eye in order to prevent metastasis of cancer and to save human life [6-8]. Many different ophthalmologic ultrasonic systems are also known. The limitations of the existing in the market ultrasonic diagnostic systems have been analyzed in [9]. In this paper the new ultrasonic imaging system for capturing and processing of radio frequency signal has been proposed.

Experimental research has revealed the tasks of improvement of the developed system, like reduction of the noise level of the preamplifier, optimization of the time varying gain profile, selection of cut-off frequencies of the band-pass filters and necessity to acquire the signals reflected from the internal structure of the eye.

This paper discusses the design and development of the ultra-low noise preamplifier for medical applications.

The design methodology of the low noise preamplifier

Raišutis et. al. described the system of eye tumour diagnostic which consists of the conventional ophthalmologic scanner, the ultrasonic probe (array of transducers), the splitter to acquire raw signals, the preamplifier for initial amplification and the main data acquisition unit for digitization and storage [9]. The ultrasonic transducer was excited by a pulse having the central frequency of 10 MHz. The reflected signals from the segments of the eye were amplified in the external preamplifier (40 dB) and transferred to the main data acquisition unit. The operations of filtering (in the frequency band 7.5-15 MHz) and digitization (using

sampling frequency of 200 MHz) were performed. Further, the signals were stored in a memory of the data acquisition unit, transferred to an external computer for processing and visualization in forms of A-scan and B-scan. The quality of the A and B-scans largely depends of the signal to noise ratio (SNR) of the reflected informative signals. The reliable solution is selection of analogue components of the preamplifier possessing as low noise level as available in the market of electronic components supply, simultaneously, well known techniques of noise reduction should be used also.

In recent literature, several designs of low noise preamplifiers (LNA) were proposed [10-14]. It is designed according the following criteria that ensure the LNA performance:

- amplifier input equivalent noise;
- required preamplifier gain;
- bandwidth independent with gain;
- input impedance;
- recovery time.

Major manufacturers of integrated circuits have commercially available very low noise operational amplifier versions which are suitable to be used together with ultrasonic receiving transducers. The parameters of popular amplifiers are presented in Table 1.

Different authors reach their goals by using different types of the preamplifiers. A method to design an ultra low noise amplifier has been presented in [10]. In this work has been selected operational amplifier OPA657 (Texas Instruments). The gain of the preamplifier is 38.5 dB, bandwidth limited at low frequency from 128 kHz and upper frequency up to 2.2 MHz. Factor of native noise is established of 2.6 dB.

Other work by the same authors presented the low noise preamplifier with CLC425 (National Semiconductor) [11]. This amplifier works with the center frequency at 1 MHz and with a bandwidth of 1 MHz. The circuit has gain approximately of 40 dB. The input-referred noise of $1 \text{ nV} / \sqrt{\text{Hz}}$ is achieved at higher frequencies.

Table 1. Commercially available LNA and their parameters

Amplifier	Gain bandwidth, MHz	Input voltage noise, nV/ $\sqrt{\text{Hz}}$	Slew rate, V/ μs
LMH6624	1500	0.92	350
LMH6553	900	1.2	340
MAX4106	350	0.75	275
MAX4107	300	0.75	500
AD8099	700	0.95	475
TSH300	200	0.65	230
OPA847	3900	0.85	950
EL5133	670	0.9	1000
CLC1001	2100	0.6	410
CLC1002	965	0.6	170
LT6200-10	1600	0.95	340
CLC425	1900	1.05	350
THS4513	1600	2.2	5100
CLC5509	45	0.58	-

The most popular low noise preamplifier is LMH6624 (National Semiconductor). One of the suitable designs of the preamplifier circuit is presented in [12]. The bandwidth reaches 26 MHz at -3 dB level. The amplifier has a constant gain within the measuring bandwidth of 56.3 dB. The total noise factor is set to the minimum value of 1.64 dB. The second design is described in [5]. The bandwidth of this preamplifier is between 150 kHz and 2.5 MHz. The

obtained gain of the amplifier was 40 dB and the noise factor was 1.9 dB.

A novel design of a low noise amplifier for medical ultrasound is described in [13]. The design employs the operational amplifier (OPA2658, Texas Instruments) in order to enhance the gain within the bandwidth and to improve the slew rate of the schematic. The simulated circuit has a bandwidth until 10 MHz and the noise voltage spectral density is less than 1 nV/ $\sqrt{\text{Hz}}$. It has an electronically adjustable matching resistance also.

The preamplifier design

The design of the low noise preamplifier for eye tumour diagnostic system must meet the requirements described above: the gain about 40 dB, the bandwidth between 5 and 20 MHz, a low cost design and a high SNR. In order to construct the circuits possessing such requirements two schematics we analysed.

The performance of the LNA was improved using the two stages preamplifier. The noise factor of the two stage amplifier can be determined by the following Friss formula [12]:

$$F_{\Sigma} = F_1 + \frac{F_2}{A_1}, \tag{1}$$

where F_1 and F_2 are the factors of noise of the first and second stages, A_1 is the amplification factor of the first stage. Since the A_1 have the high value, F_{Σ} is very close to the first stage noise factor. In the first and second stages we introduce the low noise circuit OPA847 (Texas Instruments). Such preamplifier circuit diagram is presented in Fig.1.

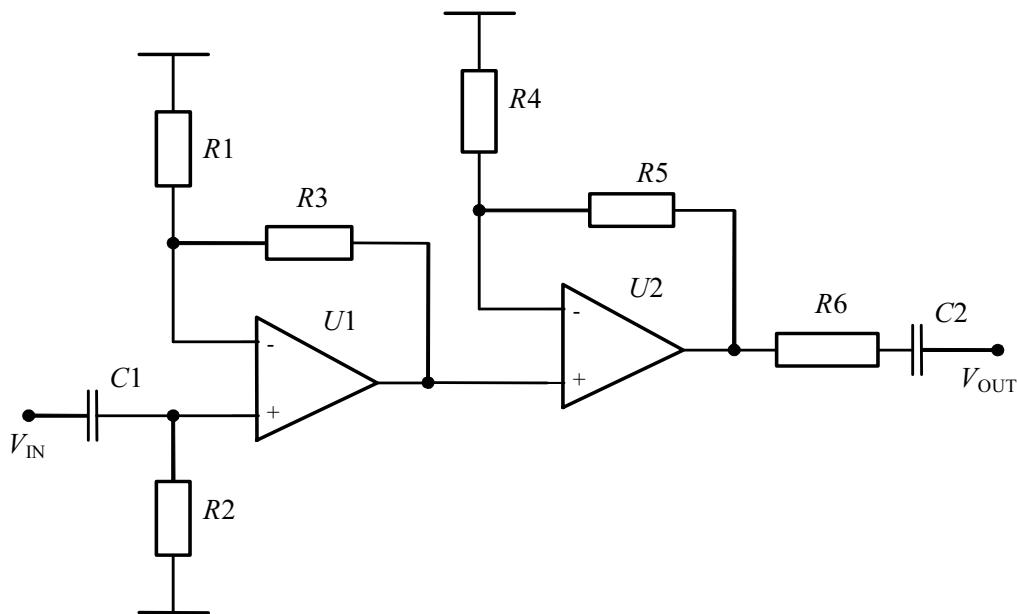


Fig.1. The circuit of two stage low noise preamplifier.

The noise factor (in dB) of the amplifier is defined by expression [15]:

$$F = 10 \lg \left(1 + \frac{U_{pr}^2}{U_{Rn}^2} \right), \tag{2}$$

where U_{pr} is the noise voltage at the output of the amplifier, U_{Rn} is the noise voltage of the external resistor.

The thermal noise generated by any external resistor R_e is given by [14]:

$$U_{Rn} = \sqrt{4KTR_e \Delta f}, \tag{3}$$

where K is the Boltzmann's constant, T is the temperature in Kelvin, R_e is the resistance, Δf is the noise bandwidth in Hz.

The gain of the designed preamplifier was about 36 dB within the frequency bandwidth from 2 to 25 MHz. The calculated noise factor has been about 2.5 dB. Unfortunately, the noise factor did not meet our requirements.

In order to solve this problem, the analysis of different low-noise preamplifier circuits was performed and promising results were obtained. For the preamplifier schematic the design of low frequency amplifying circuit described in [16] was applied. This circuit reduces the amplifier noise by \sqrt{n} , where n is the number of

amplifiers. The problem of the design of this circuit is to bring into synchronization the phases of input signals of different amplifiers. In such a way the amplifier noises are uncorrelated and reduced by \sqrt{n} .

The proposed circuit of the ultra low-noise preamplifier is presented in Fig.2. This preamplifier consists of four identical amplifiers CLC1001 with input voltage noise of $0.6 \text{ nV}/\sqrt{\text{Hz}}$ (Table 1) and a summation amplifier. The measured gain of the circuit is about 48 dB, the bandwidth between 2 and 35 MHz. The noise factor of the first stage reaches the lower value of 0.46 dB.

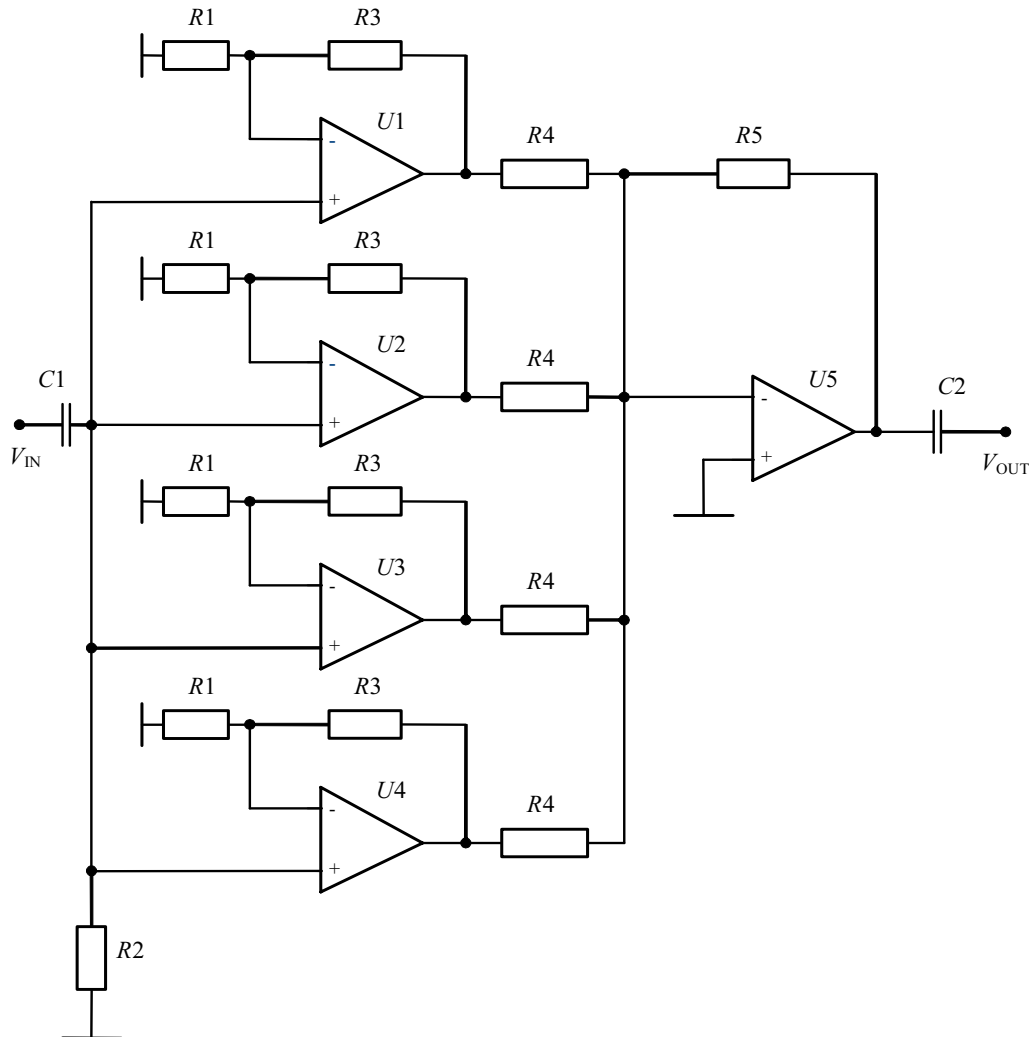


Fig.2. Ultra low-noise preamplifier circuit composed of four identical preamplifiers.

Conclusions

The solution of the problem in order to improve the SNR of the ultrasonic eye tumour diagnostic system has been proposed which enables reduction of the noise level of the preamplifier.

Application of the low frequency amplifying principle was proposed to be used for design of schematic of the high frequency preamplifier and consists of four identical amplifiers. The final design of preamplifier allowed to

achieve the noise factor value of 0.46 dB with 48 dB gain and the bandwidth of 2-35 MHz.

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Ultragarsinės medicininės diagnostikos sistemos mažatriukšmio stiprintuvo projektavimas

Reziumė

Piktybinių akies navikų ultragarsinės diagnostikos sistemos eksperimentiniai tyrimai parodė, kad viena tolesnių sukurtos sistemos tobulinimo užduočių – pradinio stiprintuvo triukšmo lygio mažinimas. Šiai užduočiai spręsti prireikė atlikti šiuo metu rinkoje esančių mažatriukšmių analoginių komponentų atranką ir pritaikyti šiuolaikinius stiprintuvų savųjų triukšmų lygio mažinimo metodus. Atlikus teorinę analizę ir praktinius eksperimentus, buvo sukurtas mažatriukšmis pradinis stiprintuvas, įgalinantis pasiekti 0,46 dB triukšmo faktoriaus vertę 2-35 MHz dažnių juostos plotyje, kai stiprintuvo stiprinimo koeficientas siekia 48 dB. Suprojektuotas stiprintuvas remiasi žemojo dažnio stiprintuvų projektavimo schema, kai sujungus kelis stiprintuvus lygiagrečiai, bendras savųjų triukšmų lygis sumažėja \sqrt{n} kartų; čia n – sujungtų stiprintuvų skaičius.

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