THE INVESTIGATION OF ULTRASONIC PREAMPLIFIER COMPLEX PERFORMANCE

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Abstract

Ultrasonic preamplifier operating in a pulse-echo mode is analyzed. Due to the presence of high energy excitation pulses at the preamplifier input a protection circuit is required. The noise, bandwidth, input impedance and protection superiority for various preamplifiers is analyzed. The input impedance, insertion gain and noise AC response were analyzed and are presented over 20kHz to 40MHz frequency range. Essential protection circuit requirements, such as protection efficiency, recovery time are discussed and experimental results presented. Brief description and explanations on equipment and techniques used are presented.

1. INTRODUCTION

Expansion of air-coupled ultrasonics [1] is raising special demands for electronics used. Because of the large difference of acoustic impedances of solid body under investigation and air, loss can reach 100dB so powerful transmitters and low noise receivers are demanded. Since conventional ultrasound equipment is not suitable here, the development of dedicated equipment was needed.

Ultrasound transmitted power is limited to certain limits in case of medical applications for the sake of tissue protection. But transmission performance improvement is important in portable equipment [2,3].

When it comes to the preamplifier operating in a pulse-echo mode [4] input circuits become more complex and design of a low noise input stage requires of a special investigation. This type of operation assumes the presence of high energy excitation pulses at the preamplifier input. Therefore the preamplifier should contain a protection circuits. The protection circuit de-rates the preamplifier noise and bandwidth performance. Proper balance should be achieved. In this paper we analyze the preamplifier performance in the presence of such protection circuitry.

2. PERFORMANCE PARAMETERS

Amplifier input impedance interacts with the source (ultrasonic transducer) electrical impedance and affects the power available at transducer transfer to amplifier. Amplifiers used in ultrasound electronics usually are voltage-sensing (operational amplifier in non-inverting topology) or current-sensing (inverting) only. As it was indicated in [5, 6], in such case amplifier input impedance should be significantly higher than the ultrasonic transducer output impedance. But when it comes to application of transmission line (usually the coaxial cable) to connect the transducer and the preamplifier the signal reflection can occur due to receiving part impedance mismatch [7]. This can be the case in transmission line length is above one tenth of the wavelength. Most popular ultrasonic transducers operate at 20kHz to 20MHz frequency range. Then maximum cable length should not exceed 1 m which is almost always the case.

The impedance, acting at amplifier input, determines the noise level. Operational amplifier intrinsic noise is modelled using voltage source e_n and current noise sources i_{n+} and i_{n-}. refer to Figure 1 for essential noise model components (full noise model is presented in [6]).

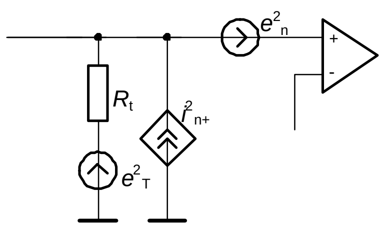

Fig. 1. Simplified noise model

If impedance can be modified using transformer then optimal impedance, acting at amplifier input, R_{opt} exists [8]:

$$R_{opt} = \frac{e_n}{i_{n+}}. \quad (1)$$

For instance, R_{opt} is 3.7MΩ for OPA657 and 400Ω for LMH6624 [9]. Contribution of various noise sources for LMH6624 at noise model [9] is presented in Figure 2. Impedance, acting at operational amplifier non-inverting input noise is labelled as NR+, impedance noise at inverting input is labelled as NR-, noise voltage source e_n contribution is labelled Nen and current noise sources i_{n+} and i_{n-} contributions is referred as Nin+ and Nin- respectively.

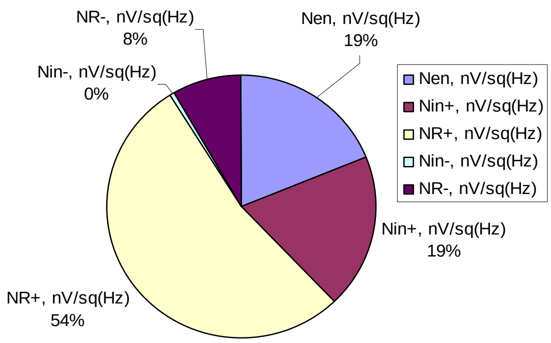

Fig. 2. Noise sources' contribution

It can be seen that contribution of source impedance thermal noise is most significant even for the case when source impedance equals R_{opt}. Otherwise it must be kept as low as possible (Figure 3).

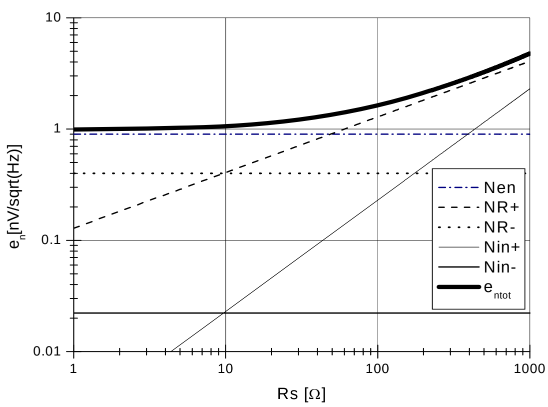

Fig. 3. Noise vs. source resistance

Analysis above indicates that preamplifier input impedance is important performance parameter. The auto-balancing bridge technique with measurement compensation using Open/Short/Load conditions [10] was chosen for impedance measurement.

The noise was obtained from amplifier gain and output noise measurement results. Sine wave [10] correlation technique was used to extract the complex signal amplitude.

To counter the high power transmission signal which is present in systems operating in a pulse-echo mode preamplifier input contains a protection circuit. The protection circuit's recovery time is important in near-field imaging. The recovery time investigation circuit is presented in Figure 4.

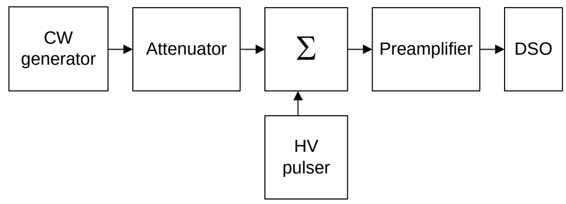

Fig. 4. Recovery time measurement

Continuous wave (CW) generator with attenuator in series is simulating the received signal. Thanks to continuous nature of CW the recovery dynamics of the preamplifier output can be evaluated by monitoring output signal magnitude. By measuring the time when signal reaches its initial level the recovery time can be estimated.

Following parameters have been chosen for performance evaluation: amplifier input equivalent noise, AC response shape, bandwidth, recovery time, input impedance.

3. PERFORMANCE EVALUATION

Olympus 5682 preamplifier (labeled Olympus), Ultratek (labeled Ultratek) and two preamplifiers of our own design (labeled LSLMH and LSAD) were evaluated. The results for gain and phase measurement are presented in Figure 5.

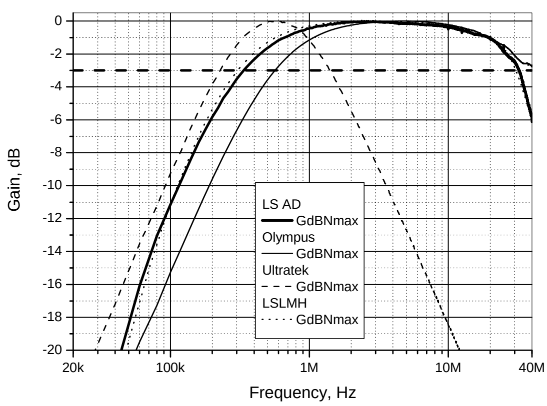

Fig. 5. Preamplifier gain curves

It could be noted that LSLMH and LSAD preamplifiers have same AC response shapes. Ultratek's bandwidth varies with gain – only maximum bandwidth curve is shown. Olympus AC response in HF end is not as sharp as LSLMH and LSAD amplifiers.

Noise measurement results are presented in Figure 6 (infinite source impedance, internal impedance present) and Figure 7 (zero source impedance).

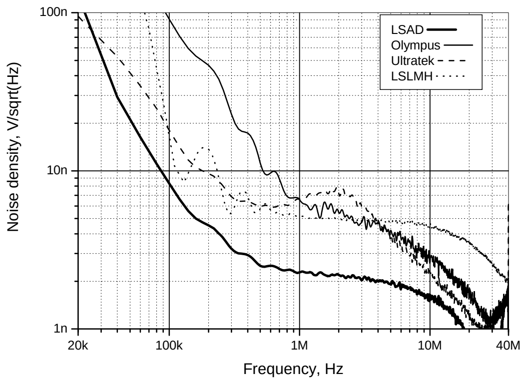

Fig. 6. Preamplifier noise curves with input circuit open

It can be seen that LSAD has lower noise density than LSLMH, Olympus and Ultratek by noise for high source impedance (Figure 6). Similar results were obtained for source with low impedance (Figure 7).

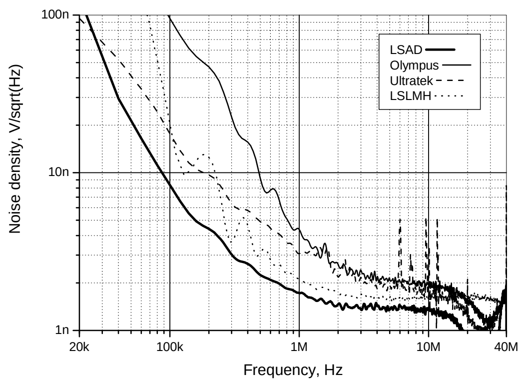

Fig. 7. Preamplifier noise curves with input shorted

Input impedance of the preamplifier is the only impedance acting at preamplifier input in case of open circuit. Measurement results are presented Figure 8.

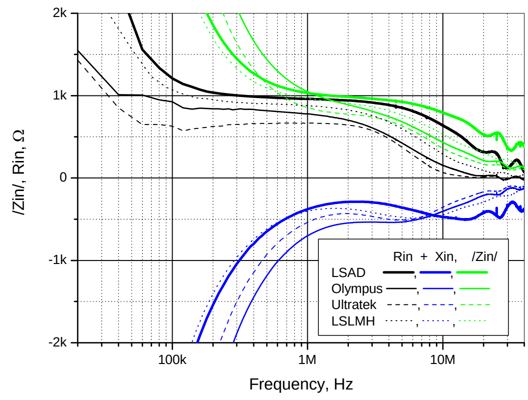

Fig. 8. Preamplifier input impedance

Investigation indicates that input impedance is stable within a passband.

The recovery time measurement results for LSLMH amplifier are in Figure 9.

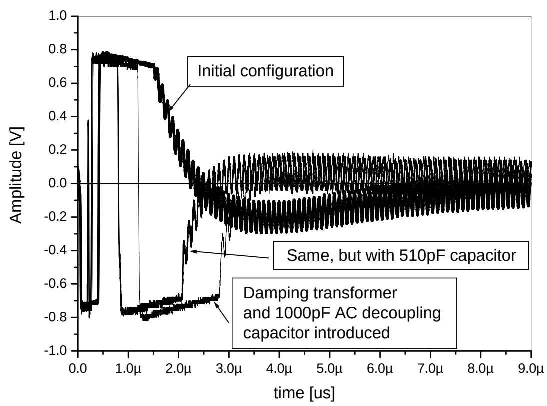

Fig. 9. Preamplifier recovery

Measured recovery times at -400V 200ns pulse were 3us for LSLMH design and 5us for LSAD preamplifier. Investigation has revealed that Ultratek preamplifier has tendency to turn into oscillations at low gains. Olympus has 1us recovery when excited from galvanically coupled pulser.

6. CONCLUSIONS

The input impedance, insertion gain and noise AC response analysis over 20kHz to 40MHz frequency range is presented. Brief description and explanations on equipment and techniques for ultrasonic preamplifier's performance evaluation is given and different manufacturers' products comparison has been established.

Results show that the noise performance is achieved with LSAD. Best recovery performance is for Olympus equipment.

References

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